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INVESTIGATION OF TWIN-SPOOL TURBOPUMP PERFORMANCE

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FOREWORD

The investigation described herein, which was conducted by the Propulsion Division of the Aerojet-General Corporation, Sacramento, California, was performed under Contract NAS 3-11231. The work was done under the management of the NASA Project Manager, Mr. W. A. Rostafinski of the Chemical Rocket Division, NASA-Lewis Research Center. The information contained in this report, NASA-CR-72540, was originally published in draft form as an internal Aerojet-General report (No. 9400-16) on 10 April 1969.

The authors wish to express their appreciation to the Space Nuclear Propulsion Office of NASA for their permission to use the main stage turbopump and the testing facility as well as providing the necessary test propellants. This program would not have been possible without their cooperation.

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ABSTRACT

The performance of a Twin-Spool Turbopump, wherein a gas turbine coaxially drives the inducer, was investigated as part of a study to evaluate various zero Net Positive Suction Pressure (NPSP) feed systems. Steady-state and transient tests were conducted in liquid hydrogen and the results were used to refine a computer program that predicts the performance of the Twin-Spool Turbopump. In addition, the extension of the operating range at zero NPSP (as compared to conventional pumps) was investigated along with the effect of varying the inducer turbine pressure ratio. It was found that the concept is applicable to the starting requirements of either chemical or nuclear engines and that the basic mechanical concept is a workable arrangement.

I. SUMMARY

The Twin-Spool Turbopump testing is part of a NASA-Lewis Research Center study being conducted to assess various propellant feed system concepts for pumping rocket engine fuels at very low and zero values of Net Positive Suction Pressure (NPSP). As used herein, NPSP is identified as the margin of propellant total pressure above vapor (saturation) pressure and is measured at the bottom of the propellant tank.

The Twin-Spool Turbopump incorporates a low-speed inducer to supply the required inlet pressure to the main pump. This inducer is driven through a shaft which is coaxial with the main shaft. The drive source is a single-stage gas turbine located aft of the main turbine.

The basic, 7 psi NPSP main-stage turbopump had been extensively tested previously at zero NPSP. Based upon existing rocket engine requirements, its performance over the desired operating range was unsatisfactory. Adding an inducer stage provided a unique opportunity for evaluating the effect of the inducer stage upon the over-all performance of the turbopump.

A high-speed digital computer program was formulated in FORTRAN IV to predict the transient and steady-state performance of the Twin-Spool Turbopump. This program was based upon inducer, pump, and turbine characteristic curves. The test data were used to refine the program until predicted performance matched the actual test results.

The following four basic types of tests were conducted in liquid hydrogen:

- Flow traverses while maintaining a constant main-stage shaft speed. NPSP values of 20 psi, 5 psi, and 0 psi (13.78 N/cm^2, 3.44 N/cm^2, and 0 N/cm^2) were mapped. In some instances, considerable vapor was ingested by the unit.

- NPSP traverses from 20 psi to 0 psi (13.78 N/cm^2 to 0 N/cm^2) while holding a constant flow and speed.

- Simulated engine start ramps of three seconds and six seconds. The terminal NPSP's for the three second ramp were 20 psi and 1 psi (13.78 N/cm^2 and .689 N/cm^2) while for the six second ramp, the terminal NPSP was 0 psi (0 N/cm^2).

- Inducer stage sensitivity tests to investigate the effect of varying the split between the main-stage and inducer stage turbine pressure ratios. This split was accomplished by utilizing orifices of various sizes to reduce the effective area of the exhaust line.

The extremes in flow rate swing also were studied. This ranged from stall at the lowest flow to the point where the pressure rise showed a moderate degradation as a result of excessive flow rate.

There was a very close correlation between actual and predicted performance, which permits the following major conclusions:

- The Twin-Spool Turbopump exhibits an essentially non-cavitating performance, both in pressure rise and flow range, while operating at zero NPSP and with moderate vapor ingestion.
- Based upon the transient start ramp response, the concept is applicable to either chemical or nuclear engine starting requirements.
- There is no problem connected with the sensitivity of the inducer stage to reasonable variations in the turbine exhaust system area.
- Twin-Spool Turbopump performance can be predicted and is a function of the accuracy of the predicted pump and turbine characteristics.
- The accumulated running time (45 min at full-speed and over 60 min total) demonstrates the basic mechanical concept to be a workable arrangement.
- The Q/N range of the inducer is narrower than found in most boost pump concepts as a result of the power being extracted from the turbine drive gas (i.e., as main pump flow and power rise, the inducer sees almost the same percentage of increase in power).

II. INTRODUCTION

This report delineates the work performed at the Liquid Rocket Operations, Aerojet-General Corporation, Sacramento, California to complete Tasks I and II of Contract NAS 3-11231 (Investigation of Twin-Spool Turbopump Performance), which was under the cognizance of the NASA-Lewis Research Center, Cleveland, Ohio. The two contractual tasks are described as follows:

TASK I - The formulation and demonstration of a computerized mathematical model for prediction of steady-state and transient twin-spool turbopump operation. Refinement of the program in Task II was contingent upon the satisfactory completion of Task I.

TASK II - Testing of the Twin-Spool Turbopump in liquid hydrogen and refinement of the computer simulation based upon actual test data.

Zero NPSP (the condition at which vehicle tank pressure equals propellant saturation pressure) turbopump operation has been identified as a valid technique for improving rocket engine performance. This is based upon strong evidence indicating increased mission reliability as a result of reduced tank/engine interaction and increased operating margins. In the case of the nuclear rocket, a substantial increase in performance appears to be possible resulting from the capability to pump tank residuals that are unavailable, because of nuclear heating, when a positive NPSP system is used.

The fundamental consideration in a zero NPSP pumping system is whether liquid hydrogen at zero NPSP can be ingested into the pumping system and then pumped to the required pressure level needed for a particular application. Results from zero NPSP hydrogen pumping tests conducted by NASA-Lewis Research Center, Aerojet-General, the Pesco Division of Borg-Warner, and during the Centaur flights provide a strong confidence in the ability to achieve satisfactory pumping at zero NPSP in an operational turbopump system. From these requirements, it can be concluded that zero NPSP can be achieved and the resultant benefits are realistic.

Recognition of these potential advantages is further evidenced by the Technology Program currently under way to investigate three low-speed inducer systems (the full-flow hydraulic turbine, the partial-flow hydraulic turbine, and the hubless inducer). As a companion concept to these systems, Aerojet-General sponsored, designed, and fabricated a conversion of a NERVA Technology Turbopump to a Twin-Spool configuration. Basically, the concept is the addition of a low-speed inducer in front of the main-stage pump. The inducer is driven by its own gas turbine, which is mounted just aft of the main-stage turbine and powered by the main-stage-turbine exhaust gas. The inducer and its turbine are mechanically linked by a coaxial shaft running through the center of the main-stage shaft.

There appears to be two distinct advantages offered by the Twin-Spool Turbopump. First, there is a minimal increase in the envelope without any additional lines or valves. Secondly, there is fast starting and steady-state response resulting from the close-coupling of the inducer turbine to the main turbine.

In addition to evolving the refined computerized mathematical model for predicting Twin-Spool Turbopump performance, this investigation provided an opportunity to evaluate the concept in context with the other indicated low-speed inducer systems being studied.

Twin-Spool Turbopump performance was established experimentally in the test program and was based upon transient and steady-state operation at NPSP values ranging from 20 psi to 0 psi (13.78 N/cm^2 to 0 N/cm^2).

The main text of this report is divided into five major areas of overall program consideration; inducer design (including test results and main pump discussion), inducer turbine design (including test results and main turbine discussion), mechanical design, testing, and the computer program with refinements. Every effort has been made to assure that each of these major areas is largely self-contained and independent of each other.

The symbols and nomenclature used throughout this report are defined in Appendix A.

III. INDUCER DESIGN

The turbopump configuration utilized in the Twin-Spool Turbopump feasibility demonstration is a coaxial design which incorporates a low-speed inducer driven by a single-stage impulse turbine. An existing positive NPSP turbopump was modified by incorporating newly-fabricated components to provide for the coaxial configuration. A cross-sectional schematic of this unit is included in the Mechanical Design discussion of this report (Figure No. 79, Section V, page 118) along with views of the assembly in the build-up stand.

The main turbopump is made up of a single-stage centrifugal pump with an integral inducer driven by a two-stage impulse turbine. A hollow shaft is used to couple the turbine to the pump through a liquid-hydrogen-cooled bearing housing.

The low-speed inducer is driven through a single-stage impulse turbine by a solid shaft, which passes through the hollow shaft of the main-stage rotating assembly. Both the inducer and the inducer turbine are supported by liquid-hydrogen-cooled bearings.

Labyrinth seals were placed at the turbine and pump ends of the main shaft to prevent turbine drive gas from entering the main pump inlet. The labyrinths are designed to provide for pressurization of the cavity between the high-speed and low-speed shafts by utilizing a portion of the main-stage bearing coolant flow.

A. DESIGN REQUIREMENTS

The inducer stage is required to produce pressurized liquid with steady and reliable NPSH from initially boiling fluid so that cavitation in the pump main stage can be greatly reduced or even eliminated. The NPSH requirements of the main stage were determined from test data and are presented on Figure No. 1, which relates the pump head coefficient to the ratio of NPSH to the inlet velocity head NPSH/$C^2m/2g$) for a family of inlet flow coefficients. The design flow rate range for the inducer was established from 45 lb/sec (20.4 kg/s) to 77 lb/sec (34.8 kg/s), because considerable cavitation on the main pump had previously been gathered and the flow range was compatible with the other low-speed inducer studies. The predicted suction performance of the main stage for 77 lb/sec (34.8 kg/s), ($\emptyset_{1T}$ = 0.11), was extrapolated from test data and is represented by the dashed line on Figure No. 1. It can be seen that the inducer stage would have to supply an NPSH of at least 15 $C^2m/2g$ or 1260 ft (384 m) to achieve acceptable pump performance. Such a head rise could be supplied by a cambered inducer. The inducer design requirements are summarized on Table I.

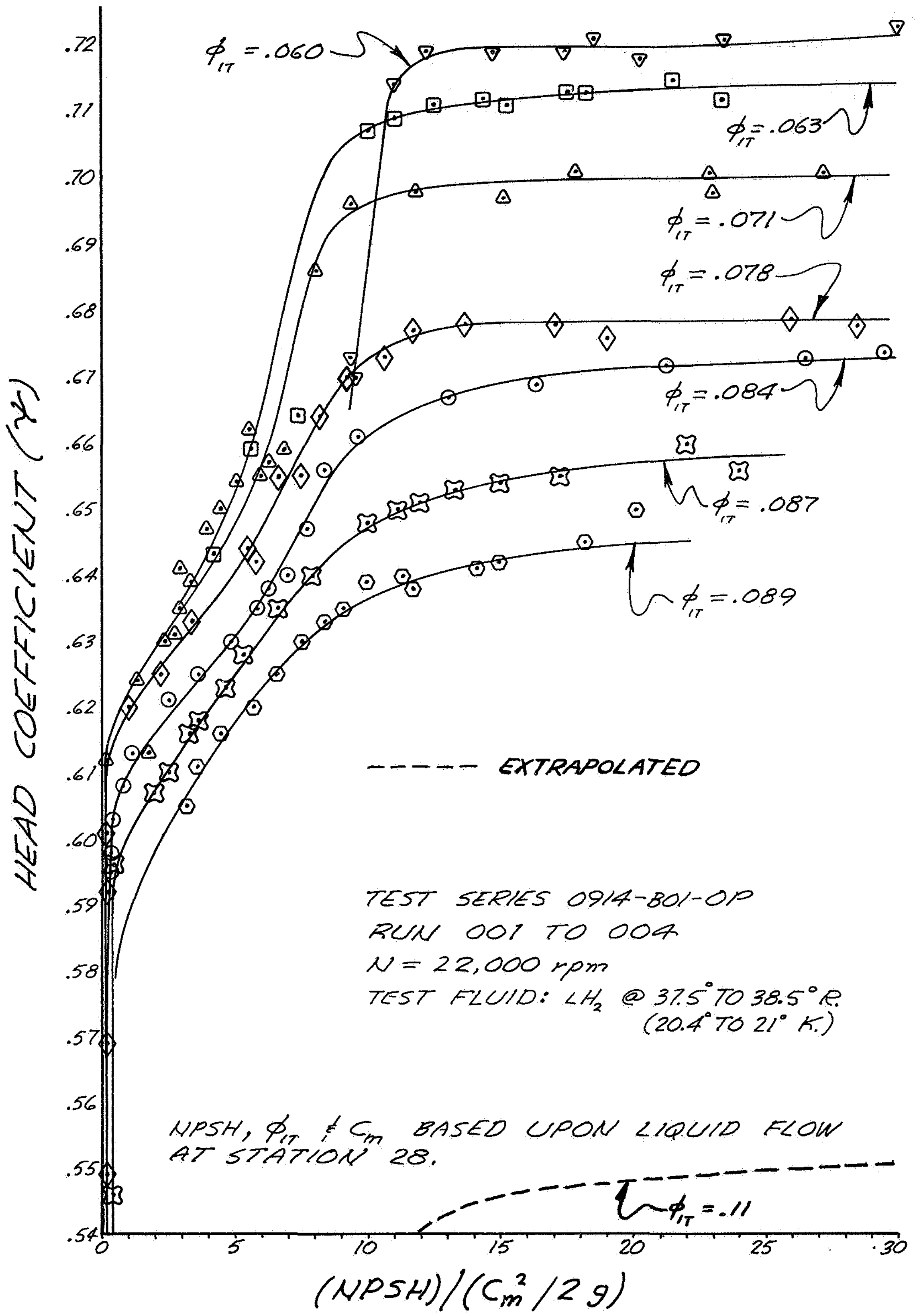


Figure 1. - Main-Stage NPSH Requirements (NERVA Low-Flow Technology Pump).

TABLE I

INDUCER DESIGN REQUIREMENTS, PARAMETERS, AND PREDICTIONS

1.	Design Requirements		
	Fluid	LH_2	
	Approximate fluid temperature	38.5°R	21°K
	Fluid density (liquid)	4.3 lb/ft^3	68.9 Kg/m^3
	NPSH	One Velocity Head	
	Maximum vapor content in percent of total volume	20	
	NPSH main-stage inlet	1260 ft	384 m
2.	Design Parameters		
	Rotational speed	10,100 rpm	105 rad/s
	Fluid velocity, inlet line (unblocked)	32.8 ft/sec	10 m/s
	Fluid velocity, inducer inlet (w/hub blockage)	39.8 ft/sec	12.1 m/s
	Tip speed	437.5 ft/sec	133.5 m/s
	Inlet tip flow coefficient	0.091	
	Incidence-to-blade angle ratio (i/β)	0.527	
	Discharge mean flow coefficient	0.20	
	Stator inlet through flow velocity (unblocked, one-dimensional)	57.2 ft/sec	17.4 m/s
	Stator discharge through flow velocity (unblocked, one-dimensional)	72.0 ft/sec	22 m/s
3.	Design Predictions		
	Over-all head rise	1305 ft	398 m
	Over-all efficiency	54.5%	
	Shaft horse power	355 hp	2.5×10^5 w
	Head loss at 20% vapor by volume	13.5%	

B. INDUCER

1. Inlet Geometry

The inducer inlet tip diameter was sized for the maximum flow rate of 77 lb/sec (34.0 kg/s), a fluid density of 4.3 lb/ft^3 (48.1 kg/m^3), a hub ratio D_{H1}/D_{T1} of 0.4, and an inlet velocity of 40 ft/sec (12.2 m/s). The inlet velocity corresponds to the limitations for low-speed inducers recommended by the NASA/Lewis Research Center (personal contacts in December 1966), namely:

Through Flow Velocity	Cm 40 ft/sec, (12.2 m/s)
Tip Velocity	U_{Ti} 500 ft/sec, (152.5 m/s)
	$NQ^{1/2}$ 10^6 rpm $(gpm)^{1/2}$
	(8.34×10^2 rad/s $(m^3/s)^{1/2}$)

The inlet velocity Cm is based upon liquid fluid, while $NQ^{1/2}$ is indirectly specified by the limits of Cm and U_T. The recommended flow coefficient calculated from the above values is 0.08, and the equivalent fluid angle is 4.658 degrees (0.0813 rad).

It is known that for a given blade inlet angle, the incidence angle determines the blade leading edge loading and the cavity shape formed. Large incident results in high leading edge loading. However, with low-speed inducers, a large incidence-to-blade-angle ratio (i/β) can be better tolerated structurally and is desired because it allows greater volumetric flow excursions or increased vapor ingestion (Ref. 1). In initial calculations, an assumed i/β value of approximately 0.6 resulted in a blade inlet tip angle β_{Ti} of 11 degrees (0.192 rad). This inlet angle was maintained in the final design as it agrees with that of a NASA inducer for which characteristic performance curves are well established. A later uprating of performance predictions dictated a decrease in the rotational speed to match the initial power requirements for the turbine. The resulting design speed of 10,000 rpm (1058 rad/s) yielded a higher flow coefficient of 0.091 and a lower i/β value of 0.527. Based upon the latter value, it was estimated that the inducer would be able to ingest approximately 15% to 20% of vapor by volume at a 10% inducer head loss at the design point. The predicted suction performance is depicted on Figure No. 2, where head loss is plotted as a function of volumetric flow.

2. Meridional Flow Path

The tip contour was maintained cylindrical, while the hub was increased towards the discharge to guide the flow around the bearing assembly. The minimum practical discharge hub diameter, therefore, was dictated by mechanical design considerations. The resulting discharge mean flow coefficient is 0.2, and the flow coefficient ratio ϕ_{2M}/ϕ_{1M} is 1.67.

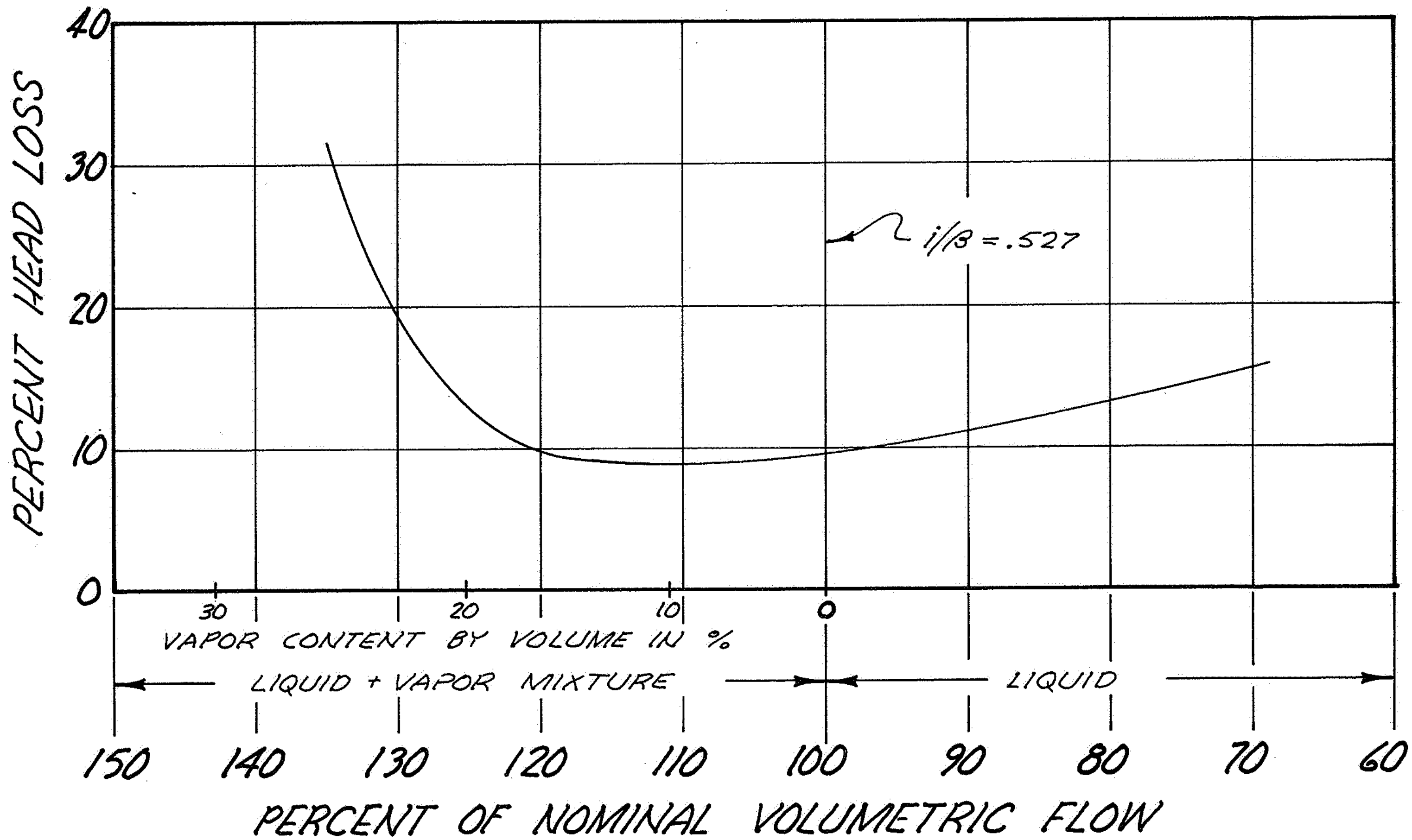


Figure 2. - Predicted Inducer Performance at Zero NPSP in Tank.

The meridional flow path is shown on Figure No. 3 and the through-flow area distributions (blocked and unblocked) are presented on Figure No. 4.

3. Blade Angle Distribution

The inducer was designed with radial blade elements (tangent of blade angle inversely proportional to radius at any axial position) for ease of manufacture. Minimum blade angle distribution was computed as a function of the through-flow area for a constant Euler head evaluated at the leading edge. The inducer discharge blade angle was increased by approximately 5 degrees (0.0871 rad) to account for channel and stator losses and to obtain an adequate NPSH margin. Final blade angle distribution was obtained by arbitrarily fairing a smooth curve from the value fixed at the discharge to the required minimum values of the inlet section. The resultant blade camber is approximately the same as that of the M-1 Fuel Pump inducer (Ref. 2). A short, helical blade section was provided at the inlet to maintain a constant passage area in the inlet portion of the blade row. The solidity of this section is approximately one at the hub and slightly lower at the tip because of the blade trim. NASA data (Ref. 3) indicate that the addition of a helical blade portion at the inlet of a similar inducer resulted in a performance gain. The blade angle distribution for the tip and the hub is presented on Figure No. 5 while the Euler's head distributions are shown on Figure No. 6.

4. Number of Blades

Four full blades and four partial blades were selected to maintain an acceptable rotor length or a reasonable L/D value for a desired over-all solidity of approximately 4.0. The four-blade inlet section and the eight-blade discharge section have approximately equal solidity.

5. Blade Shape

Improved performance and increased operating life is realized with thin blades or higher strength material. Titanium A110 basically was selected for this reason as well as its higher fatigue strength and cavitation erosion resistance. A maximum blade root thickness of 0.300-in. (0.762 cm) was extrapolated from similar inducer designs. This value is equal to approximately one-half of the cavity height at the design flow rate. The same proportions are maintained at the tip, where a thickness of 0.110-in. (0.270 cm) was established.

To simplify fabrication, the blades are designed to be machined with constant cutter offset; a method which results in a variation in blade thicknesses. A 3/8-in. (0.952 cm) tapered ball-end cutter was specified, based upon the minimum blade spacing at the beginning of the short partial blades. A nominal blade leading edge thickness of 0.010-in. (0.0254 cm) was selected for good suction performance. The blade thickness distribution is plotted on Figure No. 7.

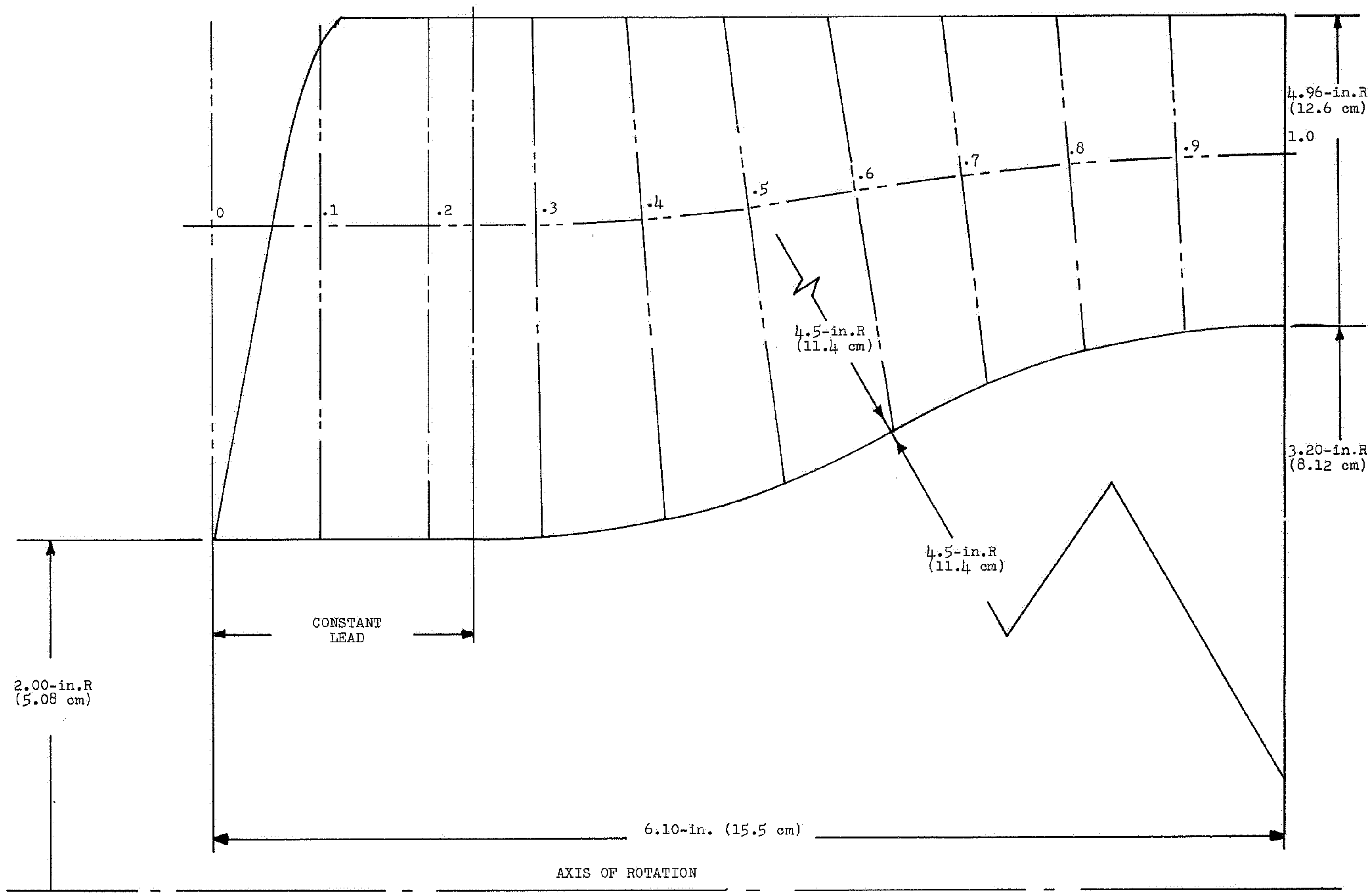


Figure 3. - Inducer Meridional Flow Path.

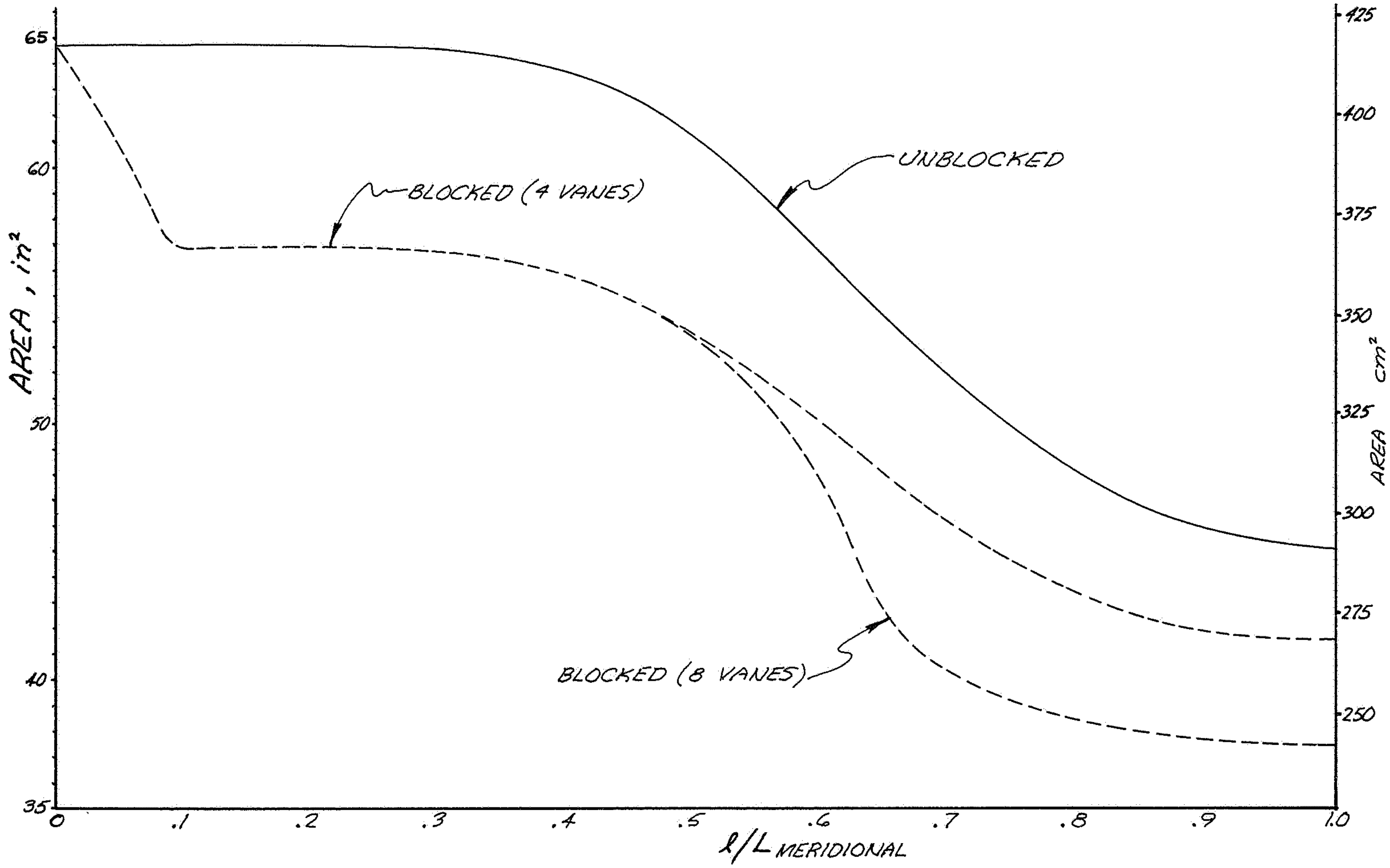


Figure 4. - Inducer Through-Flow Area Distributions.

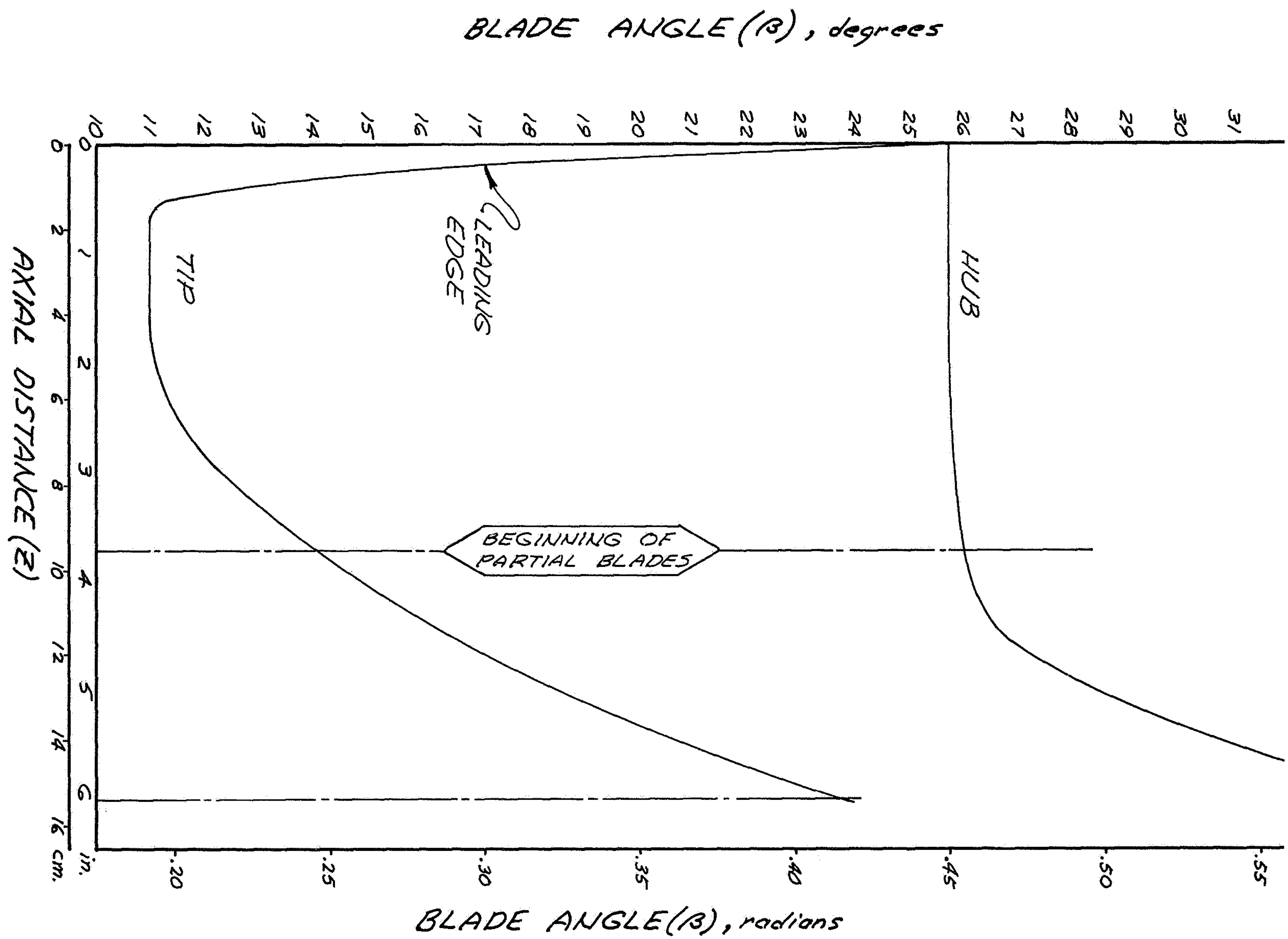


Figure 5. - Tip and Hub, Blade Angle Distribution.

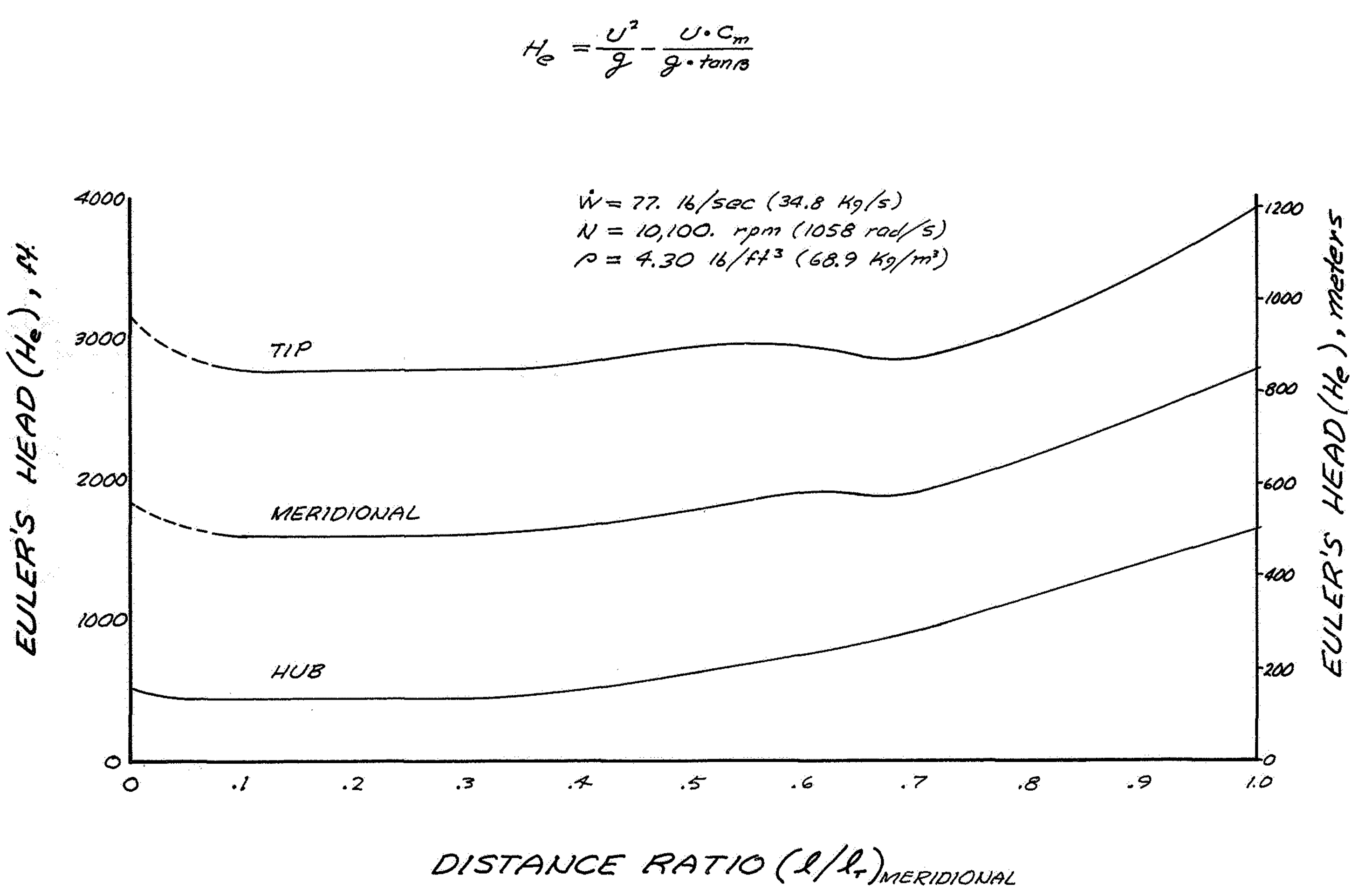


Figure 6. - Inducer Euler's Head Distributions.

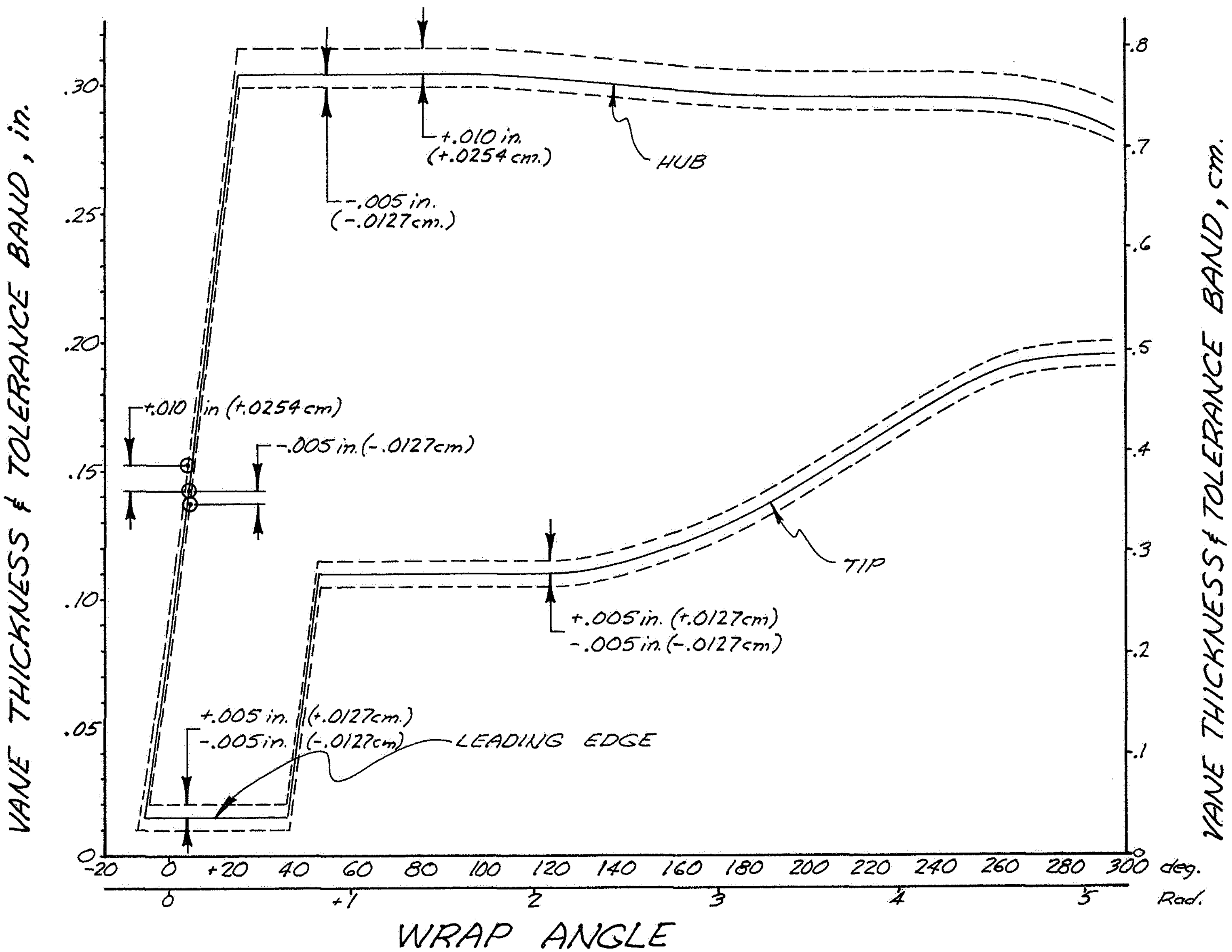


Figure 7. - Inducer Blade Thickness Distribution.

The blade inlet tip was swept back 37-degrees (0.65 rad) to improve the stress distribution in the thin overhang portion of the blade. Fairing on the low pressure side of the blade is such that the resulting wedge angle is equal to the incidence angle at 120% of the design flow coefficient.

The rotor geometry is summarized on Table II.

6. Blade Loading

The hydraulic blade loading was determined from a computer program based upon the free streamline wake theory (Ref. 4) of a flat plate. The maximum load occurs at the highest speed, lowest flow coefficient, and highest NPSH. The load analysis was conducted for the following condition:

$$\begin{aligned}
\text{Speed } N_I &= 13{,}500 \text{ rpm (1415 rad/s) (122.5\% } N_{DES}) \\
\text{Flow Rate } \dot{W} &= 77 \text{ lb/sec (34.8 kg/s)} \\
\text{NPSP} &= 50 \text{ psi (34 N/cm}^2) \\
\text{Fluid Density} &= 4.4 \text{ lb/ft}^3 \text{ (70.5 kg/m}^3)
\end{aligned}$$

Results are plotted on Figure No. 8 (as lines of constant pressure, isobars) superimposed on the blade leading edge.

7. Analysis

One-dimensional inlet and discharge velocity triangles are shown on Figure No. 9. The incidence angles of 1-degree, 3-degrees and 6-degrees (0.0175, 0.0349, and 0.015 rad) for tip, meridional, and hub were based upon a survey of flat plate inducer traverse data. A rotor hydraulic efficiency of 0.82, based upon NASA measurements (Ref. 3) rather than an average loss coefficient value, was used to calculate the actual inducer head rise.

The one-dimensional calculation was verified against a computer solution based upon simple radial equilibrium. The program used in this analysis was written for the high-speed digital computer and basically is similar to the Aerojet-General Computer Program, Job 10001, which uses the method described in Ref. 5. For simplification, incompressible and axi-symmetric flow with no streamline curvatures was assumed. The output parameters describe the flow distributions at the inlet and the discharge of the rotating blade row.

Loss coefficients and deviation angle distributions of the M-1 Fuel Pump initial design inducer were used in the analysis because of the great similarity between the two rotor configurations and the good agreement in blade camber angle. These input data are plotted on Figures No. 10 and No. 11.

TABLE II

INDUCER AND STATOR GEOMETRY

Inducer P/N 1134680-1			
Suction line inside diameter	10.000 in.		25.4 cm
Tip diameter	9.880 in.		25.2 cm
Inlet hub diameter	4.000 in.		10.2 cm
Hub ratio		0.405	
Blade inlet tip angle	11°		0.192 rad
Discharge hub diameter	6.400 in.		16.3 cm
Discharge tip angle	24°		0.419 rad
Number of full blades		4	
Number of partial blades		4	
Total number of blades		8	
Over-all tip solidity		4.0	
Stator P/N 1134695-1			
Inlet tip diameter	10.000 in.		25.4 cm
Inlet hub diameter	6.300 in.		16.0 cm
Inlet blade angle	22°		0.384 rad
Discharge tip diameter	7.050 in.		17.9 cm
Discharge hub diameter	1.720 in.		4.36 cm
Discharge blade angle	90°		1.57 rad
Maximum blade thickness	0.50 in.		1.27 cm
Number of blades		11	
Blade solidity		2.1	
Blade turning angle	68°		1.19 rad

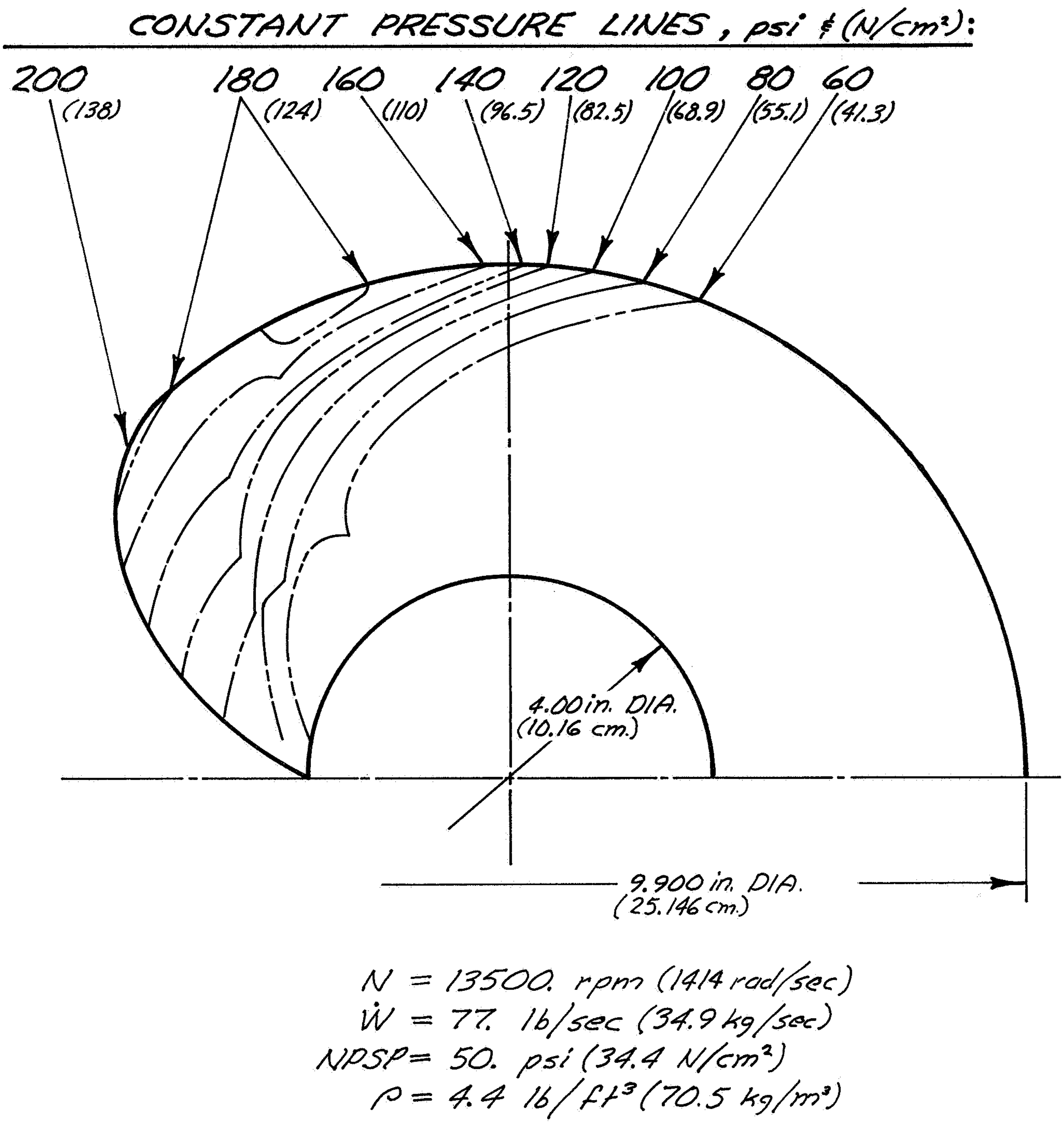


Figure 8. Inducer Blade Loading

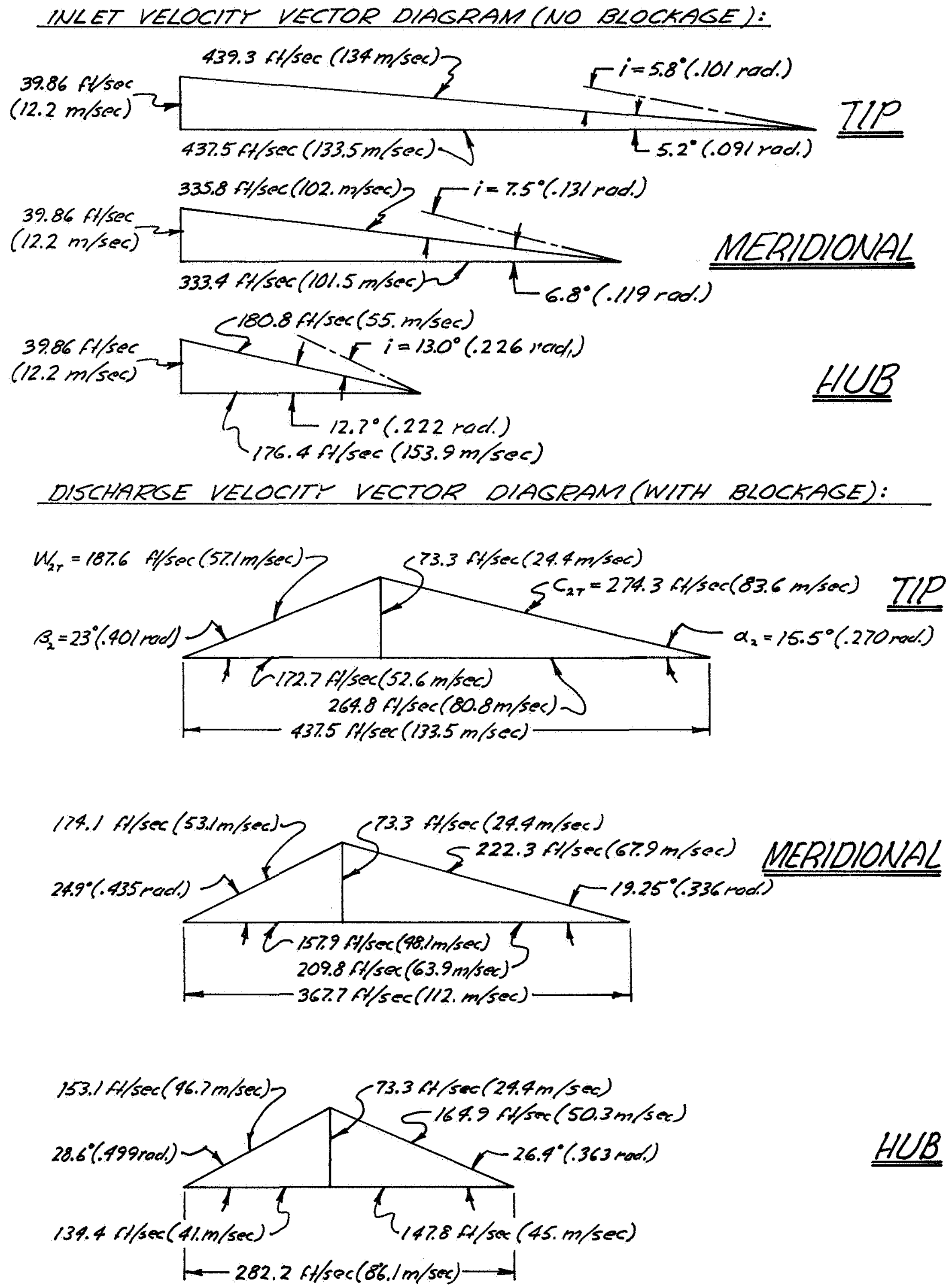


Figure 9. - Velocity Vector Diagrams.

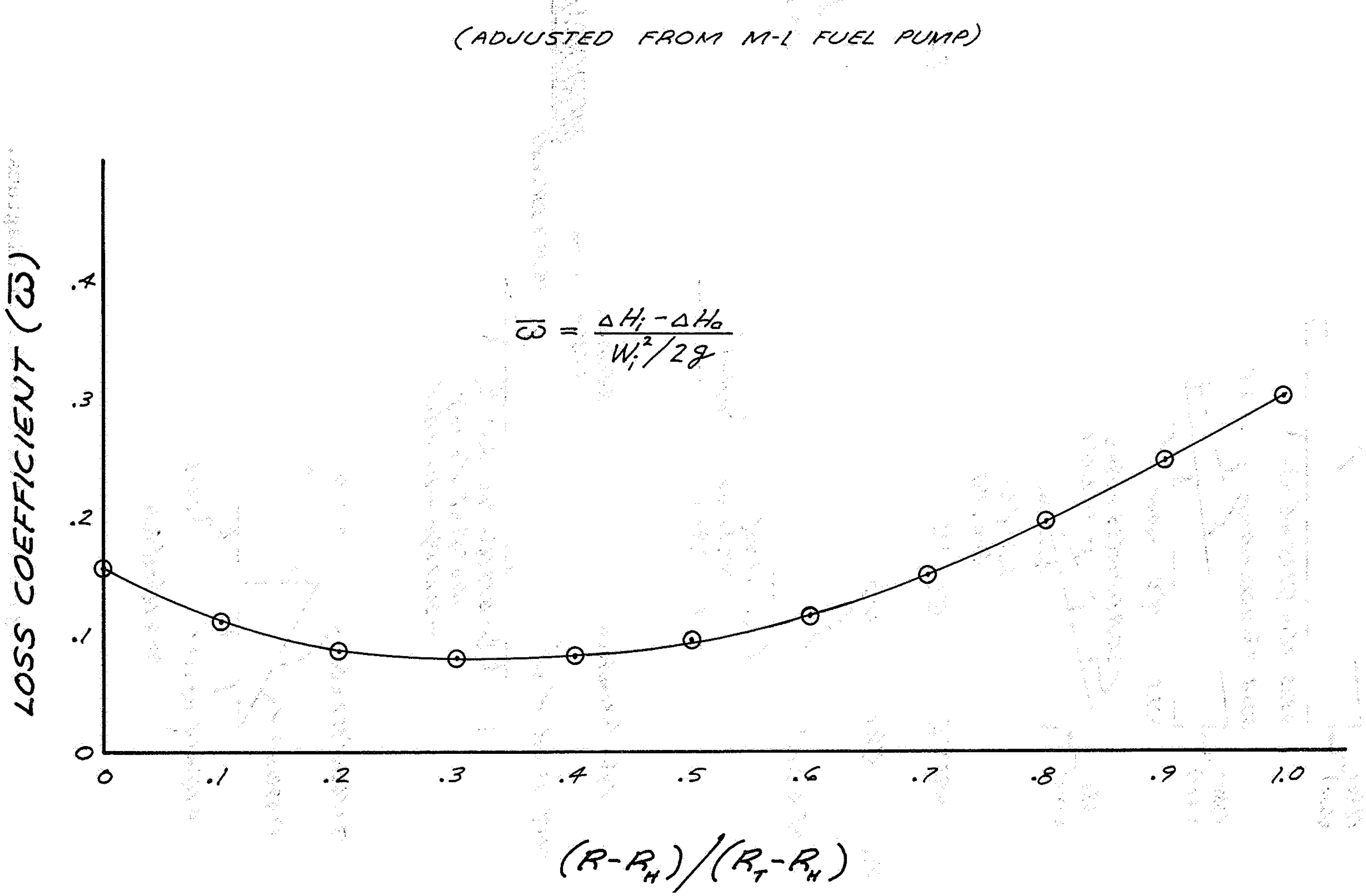


Figure 10. - Loss Coefficient vs $(R-R_H)/(R_T-R_H)$.

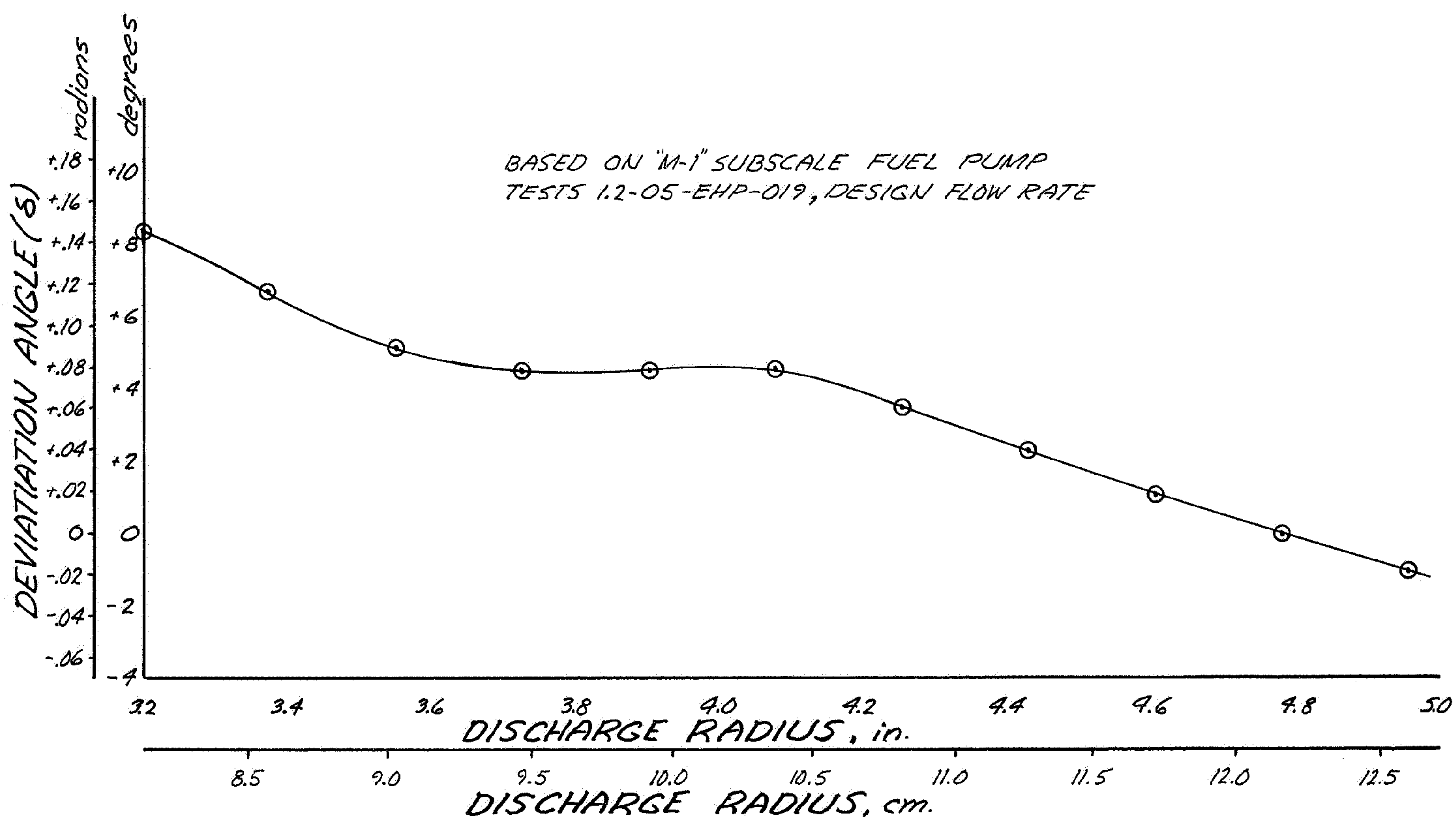


Figure 11. - NERVA Technology Pump Low-Speed Inducer Deviation Angle vs Discharge Radius.

The results are presented in terms of the through-flow velocity distribution on Figure No. 12, the absolute velocity distribution on Figure No. 13, and the absolute fluid angle distribution on Figure No. 14. The mass averaged head rise from the two-dimensional solution resulted in 2268 ft (693 m), compared with 1993 ft (608 m) from the one-dimensional analysis. It should be noted that the hydraulic efficiency of 0.82 used in the one-dimensional analysis results in a higher average loss coefficient than that represented by the loss coefficient distribution assumed in the two-dimensional analysis. Therefore, the first analysis yields a more conservative head rise. This lower value was used for predicting the stage performance. The fluid angle and velocity distributions resulting from the second analysis were considered in the designs of the inducer stator.

C. STATOR

The stator blades serve the twofold purpose of turning and discharging the fluid axially into the main-stage inlet while simultaneously providing adequate structural support for the inducer bearings. The blades also provide access routes for instrumentation and bearing coolant flow.

1. Meridional Flow Path

Inlet and discharge through-flow areas are fixed by the inducer and main-stage geometry. The shroud profiles represent gradual transitions from inlet to discharge and were shaped to provide a smooth distribution in through-flow area (see Figures No. 15 and No. 16). In the through-flow direction, the fluid is accelerated from 57.2 ft/sec (17.5 m/s) at the inlet to 72 ft/sec (22 m/s) at the design flow rate.

2. Blade Design

The blade inlet angle was matched to an average value of fluid angle with an incidence of approximately 6-degrees (0.105 rad) at the mean radius. For simplicity, the resulting blade angle of 68 degrees (1.19 rad) was kept constant from hub to tip and the blade discharge portion is axial (x = zero). The blade angle distribution at the tip follows a circular arc and is presented on Figure No. 17 as a function of wrap. Similar distributions for the mean and hub streamline are shown on Figures No. 18 and No. 19 along with the blade thickness distributions. Originally determined from a symmetrical airfoil, the thickness distributions were modified to obtain a smooth passage area distribution (see Figure No. 16). The maximum blade thickness of 0.53-in. (1.35 cm) resulted from a compromise between a good passage area distribution and a smooth blade profile as well as the requirement for routing holes. The ratio of throat area to discharge area (within the blades) was maintained to a minimum value of 0.60 to limit the degree of retardation. The stator contains 11 blades.

Stator inlet velocity vector diagrams for tip, mean, and hub streamline are shown on Figure No. 20. The diffusion factors calculated account for the change in radius and are defined as:

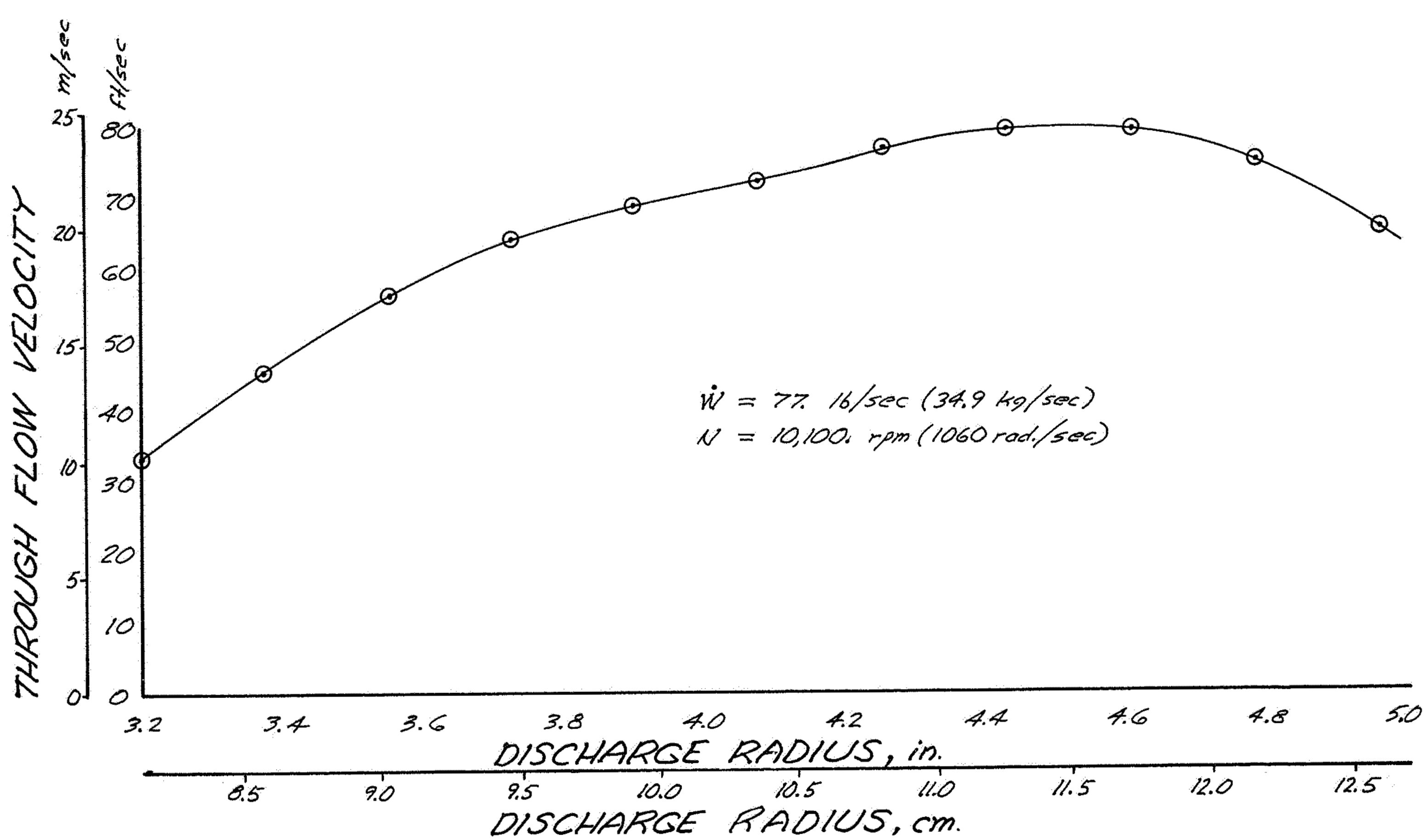


Figure 12. - NERVA Technology Pump Low-Speed Inducer Through-Flow Velocity vs Discharge Radius (Blocked).

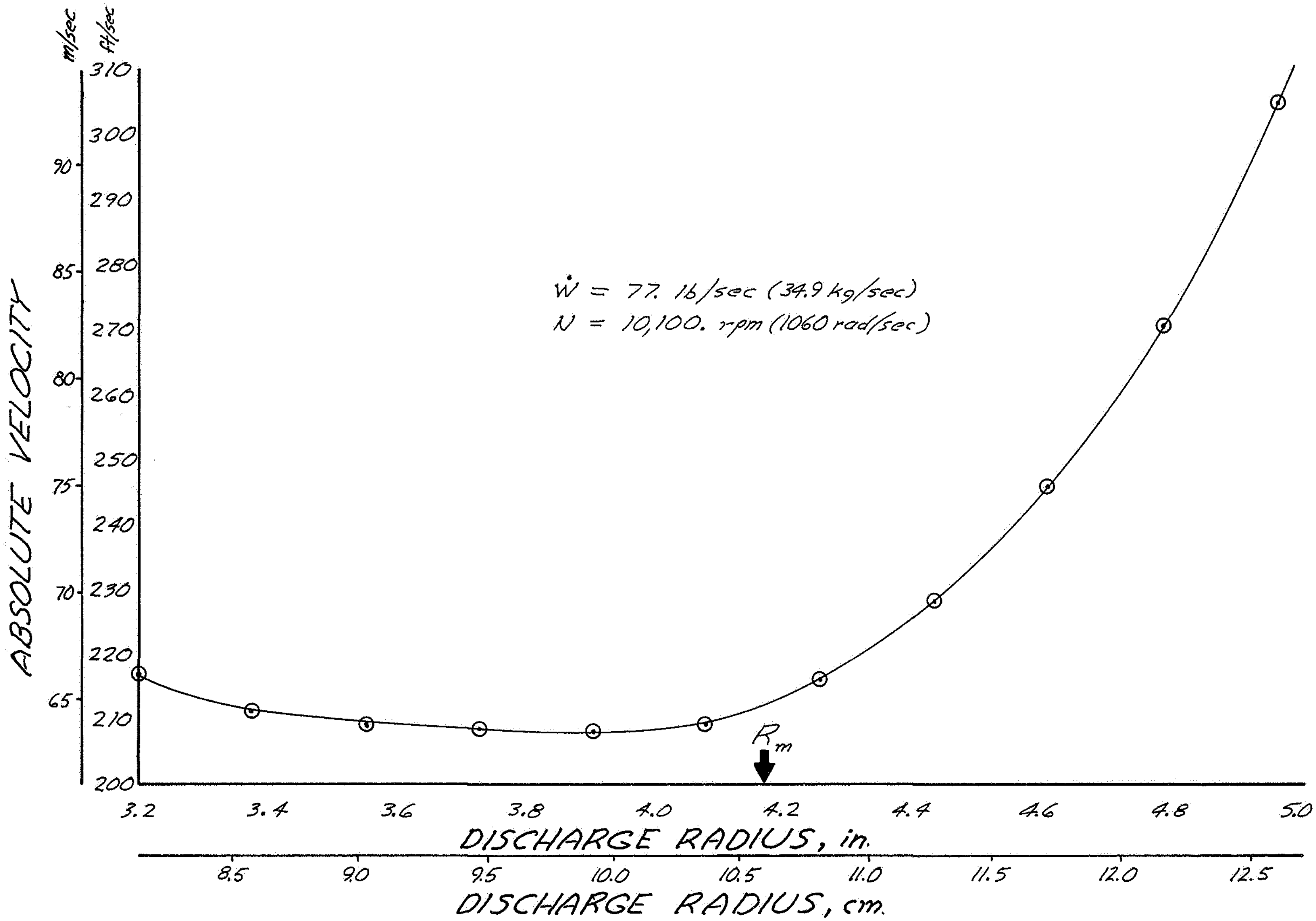


Figure 13. - NERVA Technology Pump Low-Speed Inducer Absolute Velocity vs Discharge Radius (Blocked).

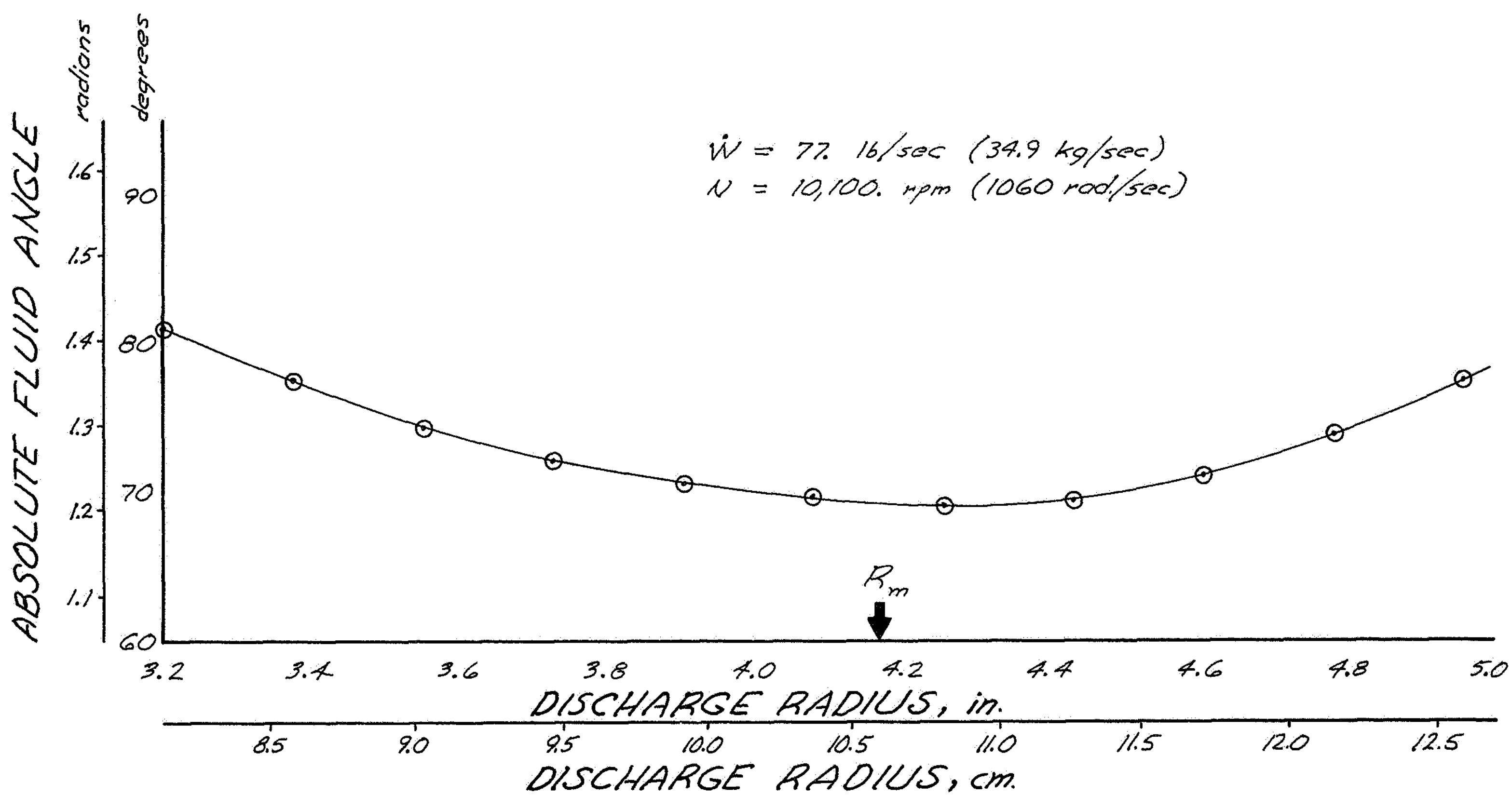


Figure 14. - NERVA Technology Pump Low-Speed Inducer Absolute Fluid Angle vs Discharge Radius (Blocked).

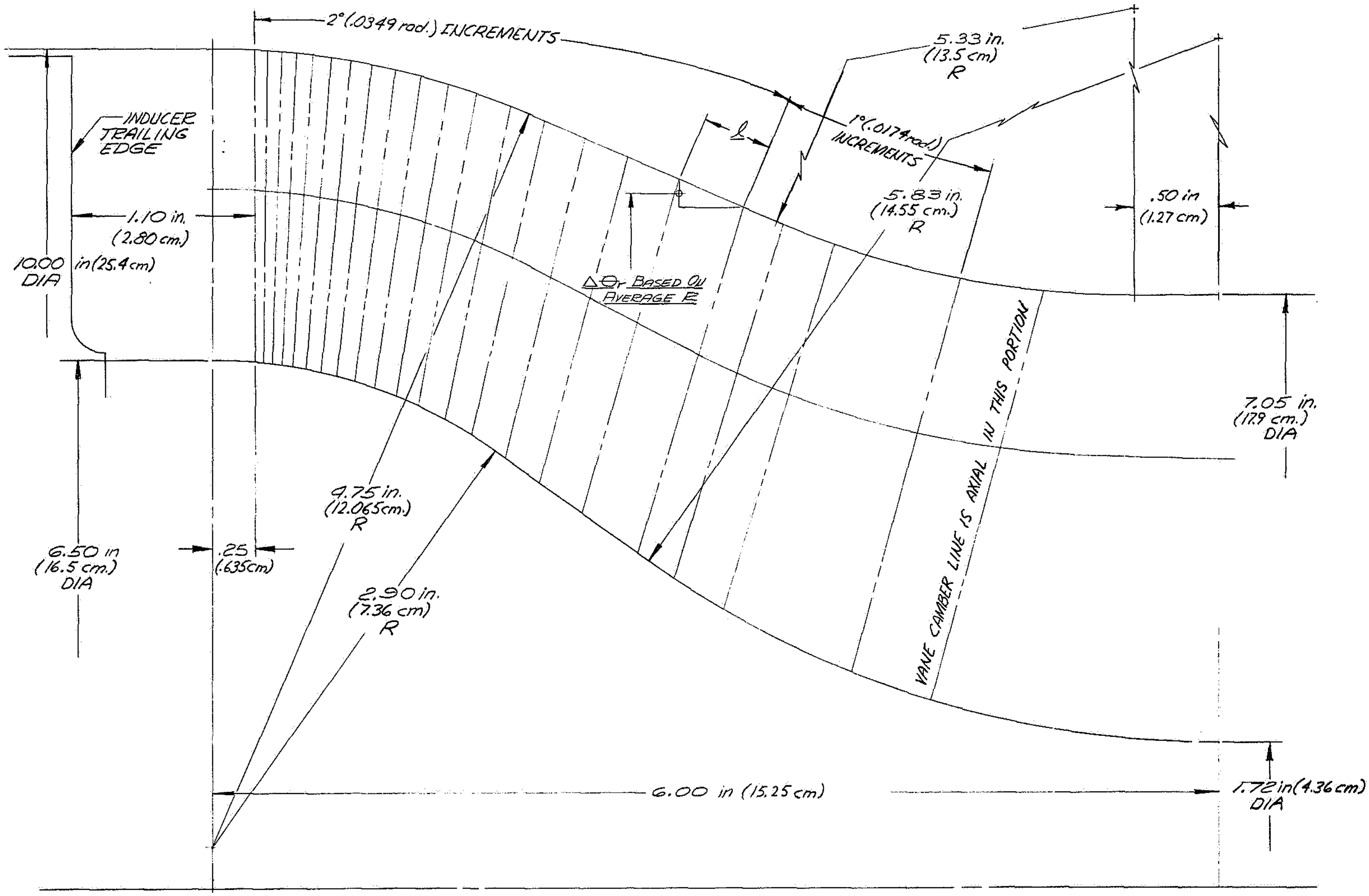


Figure 15. - Stator Meridional Flow Path.

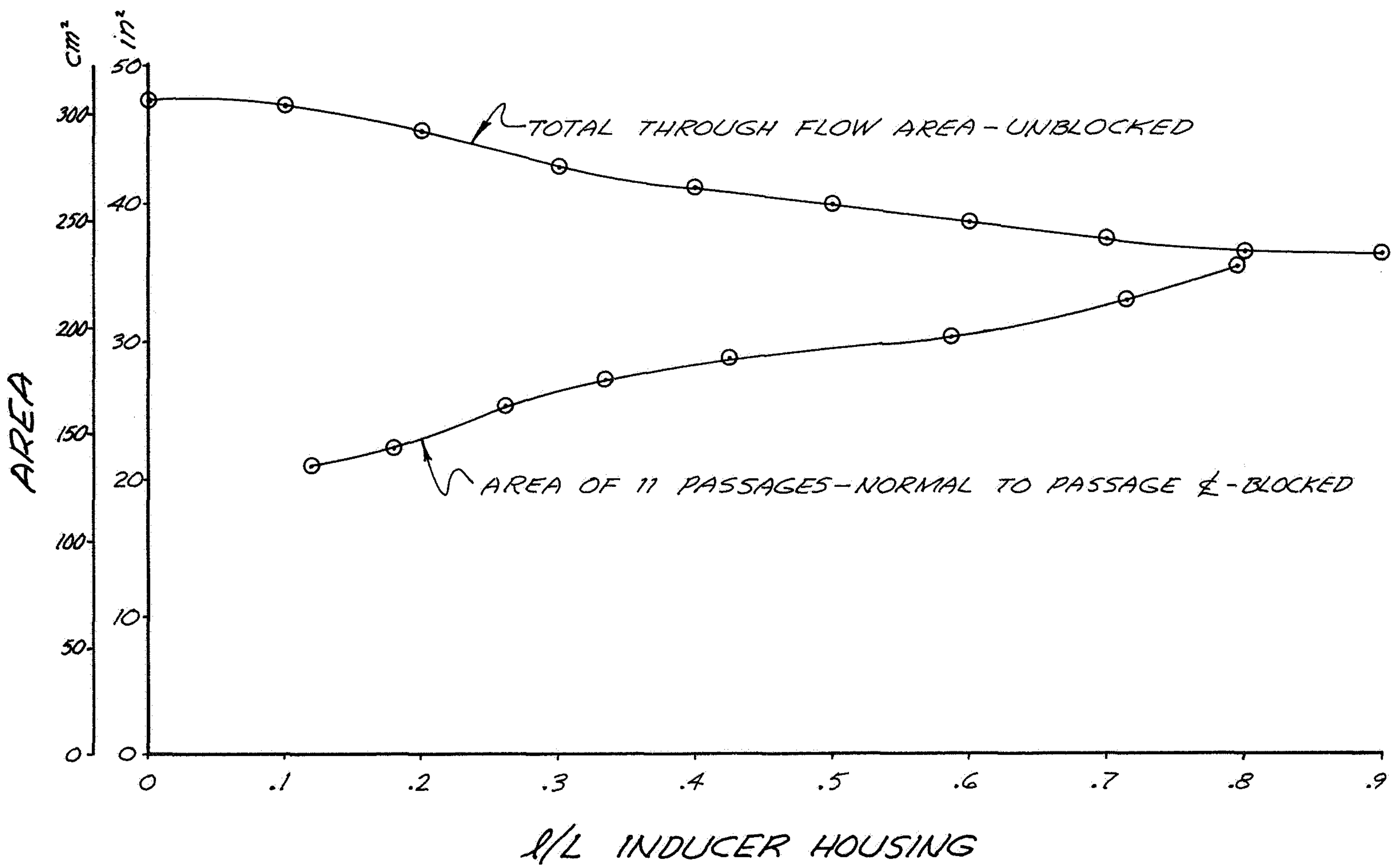


Figure 16. - Stator Through-Flow Area Distributions.

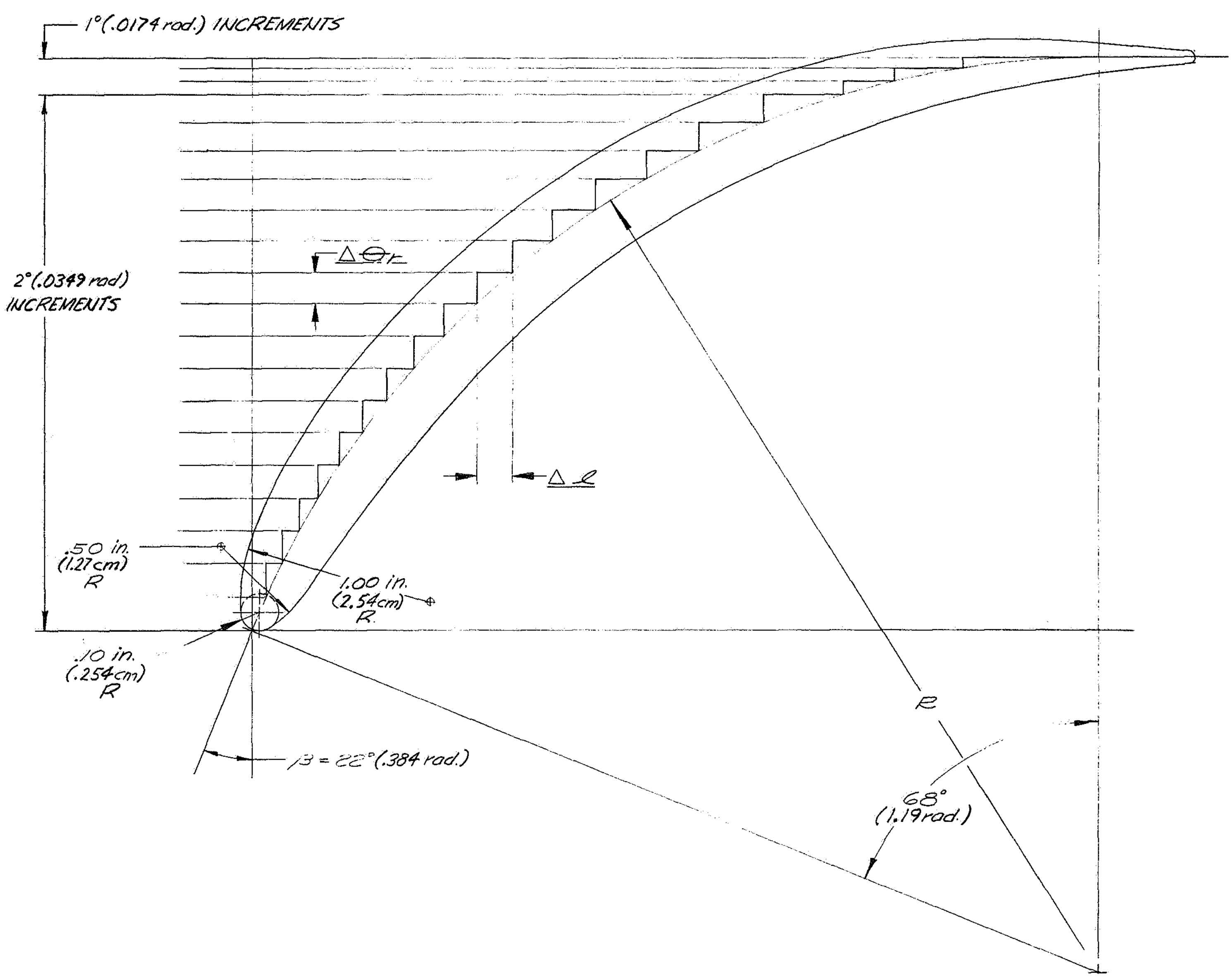


Figure 17. - Tip Angle and Thickness Distribution (2X Size).

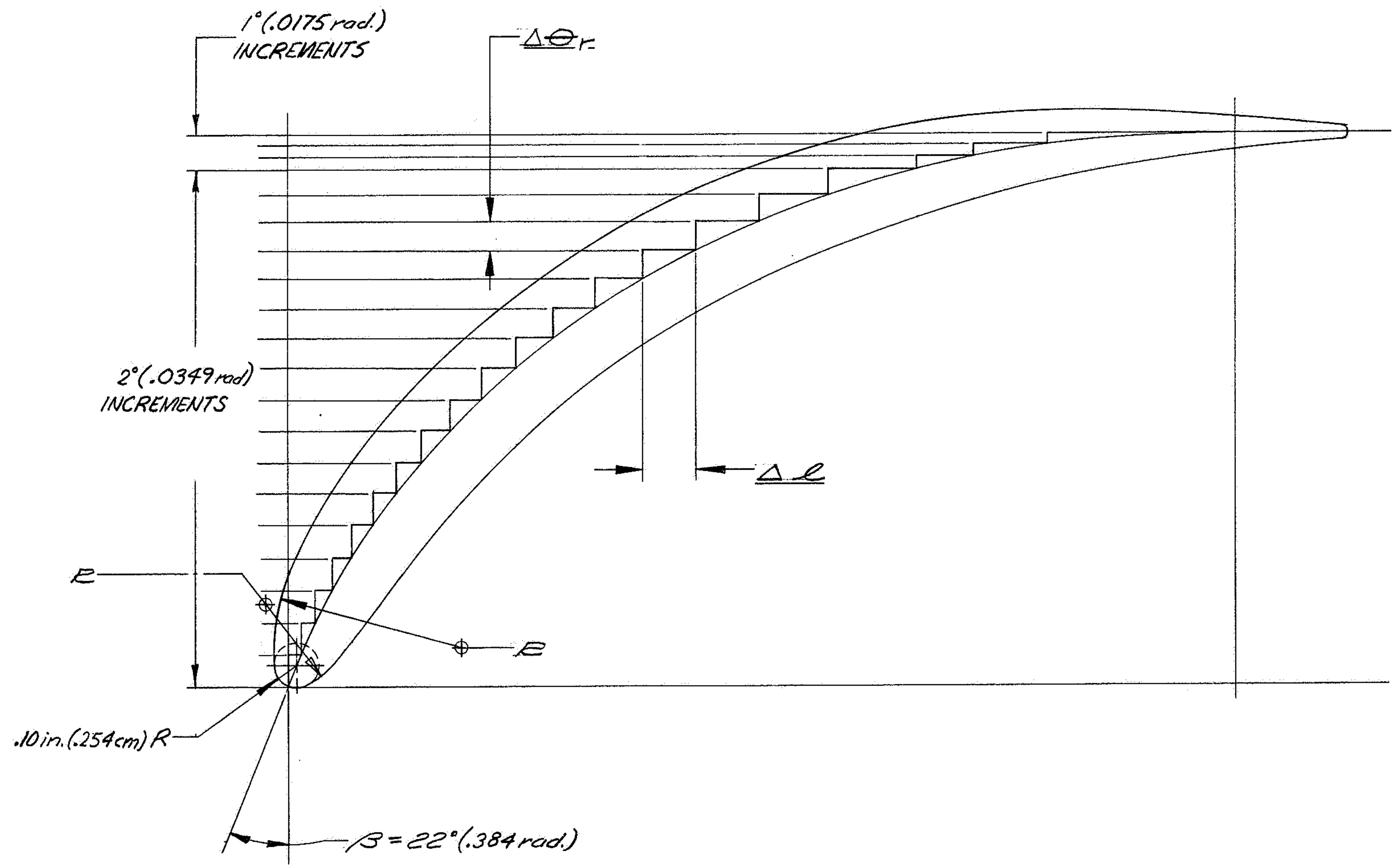


Figure 18. - Meridional β and Thickness Distribution.

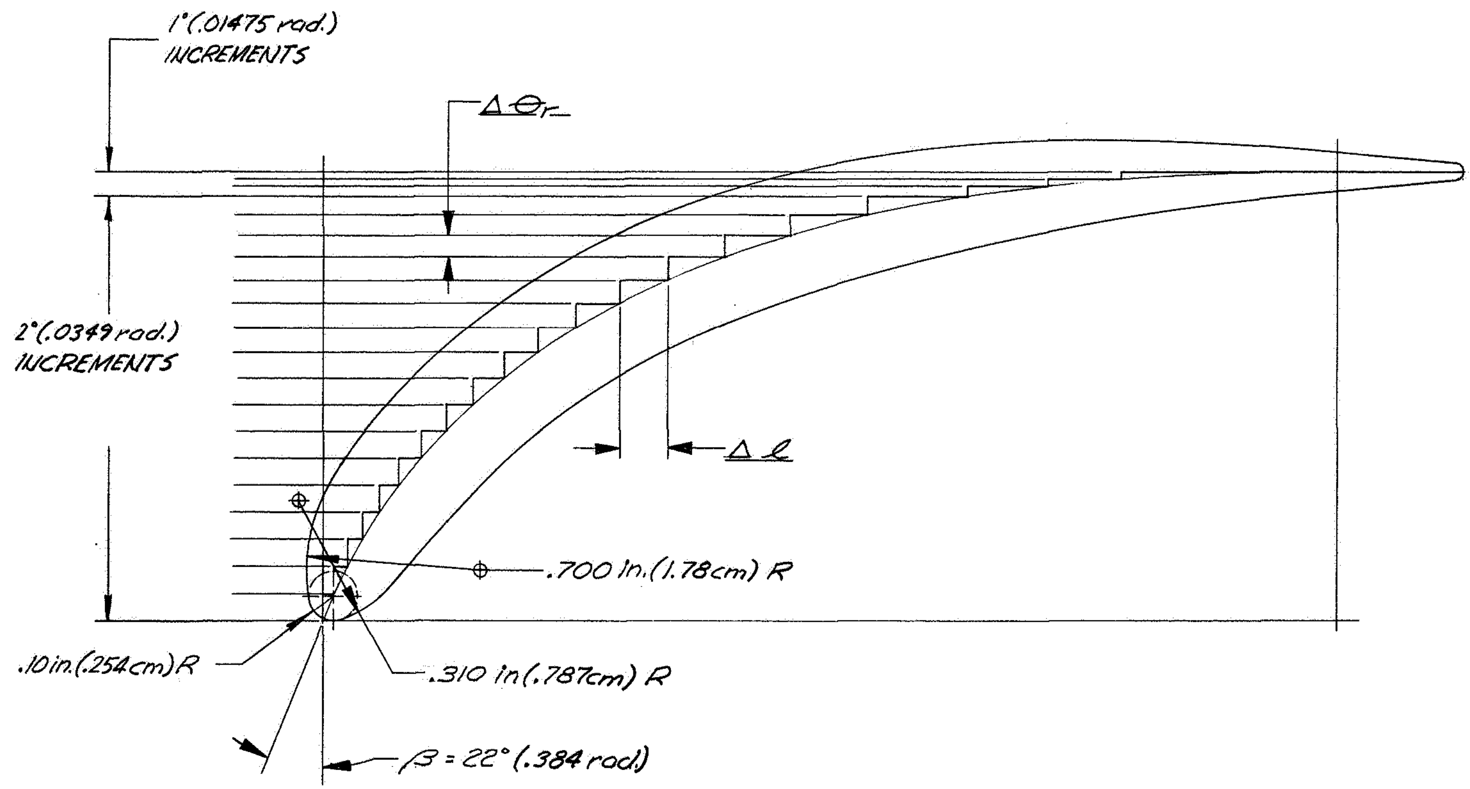


Figure 19. - Hub β and Thickness Distribution.

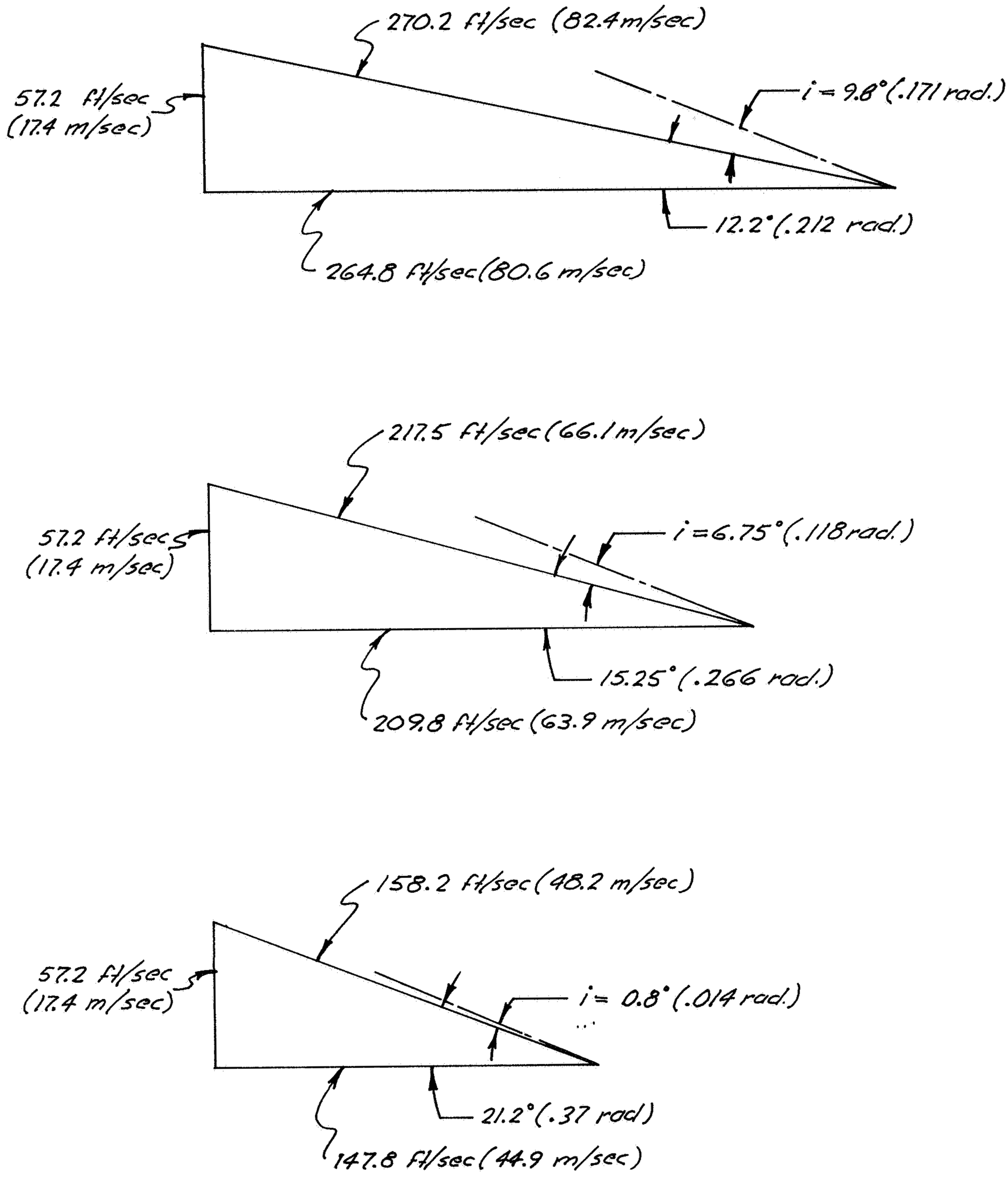


Figure 20. - Inducer Stator Inlet Velocity Vector Diagrams Assuming One-Dimensional Flow (No Vane Blockage).

$$D = 1 - \frac{V_4}{V_3} + \frac{r_3 V_{U3} - r_4 V_{U4}}{\sigma' V_3 (r_3 + r_4)}$$

For a blade solidity σ' of 2.1, the calculated diffusion factors for tip, mean, and hub are 1.0, 0.95, and 0.87. These excessive values would not be acceptable for a high performance design. To obtain lower values, the fluid turning angle would have to be lowered or either a split or tandem stator be considered.

The cavitation parameter is defined as

$$K = \frac{hs - hv}{V_1^2/2g}$$

One-dimensional calculations indicate that for all radial locations at the stator inlet, the K values are greater than one. The minimum required value of K for incipient cavitation based upon the Lieblein approximation for airfoils is 0.25.

The stator geometry is summarized on Table II.

D. DESIGN AND OFF-DESIGN PERFORMANCE

Stator performance and overall stage performance was estimated from measured and calculated data of the Hydraulic Turbine Driven Inducer (Ref. 6), which contains a similar stator design. Both stators have excessive blade diffusion and the same characteristic solidity. The predicted recovery in velocity head at design conditions is 11% and the over-all head rise, based upon the one-dimensional rotor head rise of 1993 ft (608 m), is approximately 1305 ft (398 m). Thus, the predicted non-cavitating head generating ability of the inducer stage is adequate to supply the required 1260 ft (384 m) of NPSH at the main-stage inlet. The small margin and the reasonable degree of conservatism in the prediction provide a contingency for cavitation losses. A dimensionless off-design performance comparison is shown on Figure No. 21.

The required shaft horsepower at the design condition is 335 hp (2.5×10^5W). This value is based upon an over-all efficiency of 0.545 determined from the ratio of the over-all head rise to the input head.

E. INDUCER/MAIN-STAGE PUMP EXPERIMENTAL PERFORMANCE

Generally, the performance of the over-all system, the main-stage pump, and the low-speed inducer correlated sufficiently close to the predictions to demonstrate a pumping system operational capability over the complete design flow coefficient range as well as down to tank values of NPSP that were at least as low as the design value.

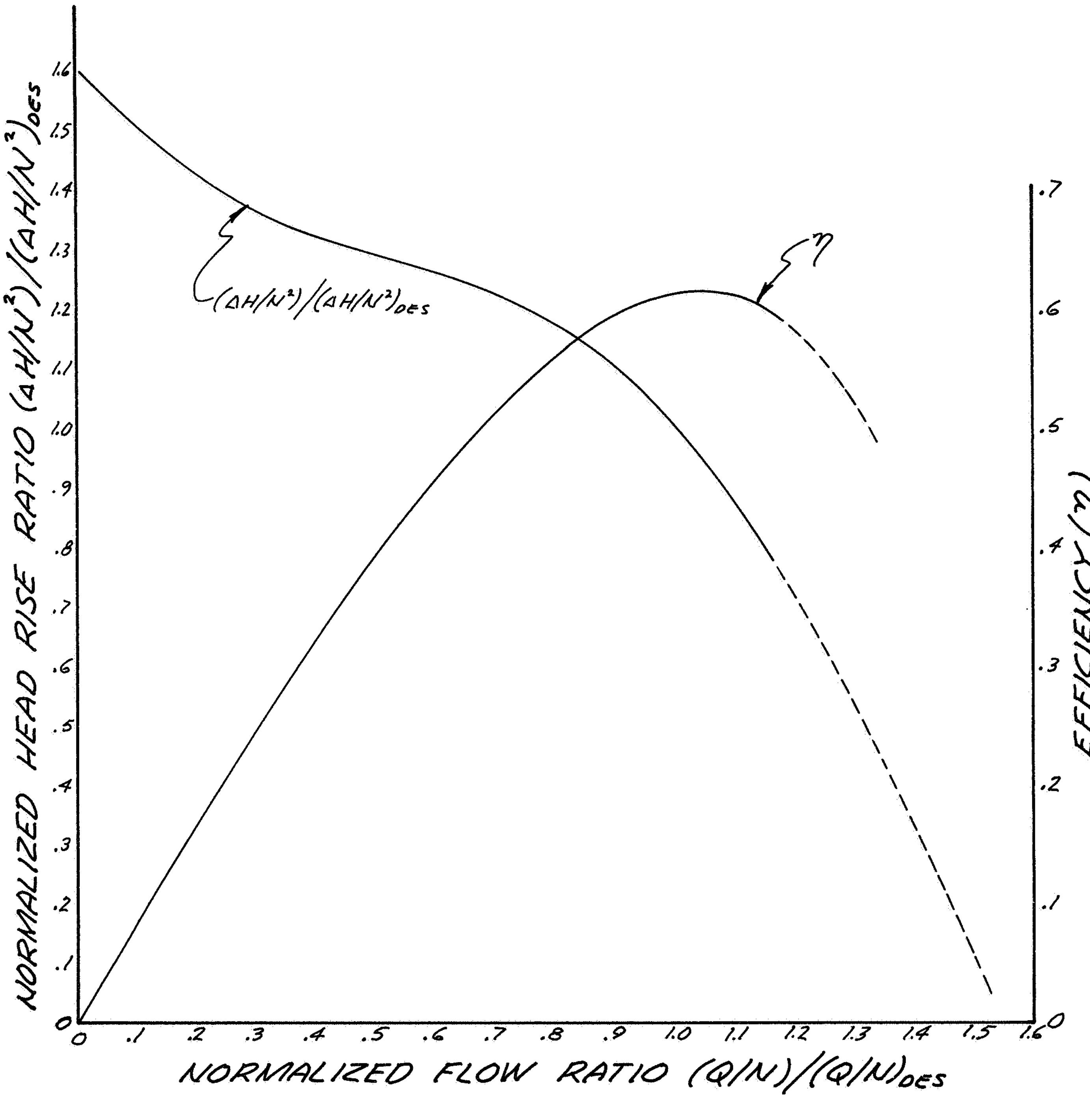


Figure 21. Predicted Inducer Stage Performance

Test speeds at the maximum flow coefficient were limited by the cold gas supply used to drive the turbine. Accurate stage performance could not be evaluated below the design flow coefficient because the temperature and pressure values recorded at the interstage (inducer stator exit) measuring station were higher than reasonable. Apparently, these conditions are caused by reverse flows exiting from the main-stage impeller. Similar conditions were experienced with the Titan I and Titan II pumps.

The ensuing discussions deal with the main-stage, low-speed inducer stage, and over-all pumping system steady-state performance results as well as system transient performance. Assumptions made in interpreting these results also are included.

1. Main-Stage Pump

Figures No. 22 and No. 23 show a comparison between the data obtained in this program and the established performance of the same pump from a previous test program (Ref. 9) in terms of head coefficient and efficiency as a function of flow coefficient. A marked difference in efficiency occurs from a flow coefficient of approximately 0.135 to 0.053. This difference is attributed to a temperature increase in the interstage, inducer-stator discharge temperature caused by reverse flows exiting from the main-stage impeller and possibly is aggravated by leakage from the inducer bearing cavity through the labyrinths. There also is some indication of an increase in pressure at this measuring station. However, the effect of the temperature increase outweighs the pressure increase, resulting in efficiency and head coefficient values that are greater than expected.

The two inducer "design points" shown on Figure No. 22 correspond to the inducer operating at the design speed and the actual speed obtained during the tests. Generally, the inducer speed was less than predicted; therefore, the main-stage flow coefficient, at which the inducer operated at design flow coefficient, is less than the original design value.

Main-stage stall was incurred during two tests, one of which resulted in an overspeed condition. The main-stage was stalled twice during test -001 at the shaft speed of 10,989 rpm (1150 rad/sec). Stall occurred at ϕ_{ms} = 0.046 at $NPSH_{tk}$ = 242.4 ft (73.88 meters) and at ϕ_{ms} = 0.048 at boiling conditions within the run tank. The stall that resulted in an overspeed condition was incurred in test -007, occurring at ϕ_{ms} = 0.052, shaft speed of 22,078 rpm (2312 rad/sec), and NPSH = 22.4 ft (6.91 meters) in the tank. The unloading of the main-stage impeller caused an acceleration rate of approximately 18,000 rpm/sec (1885 rad/sec^2). The stall points were close to those obtained in previous tests.

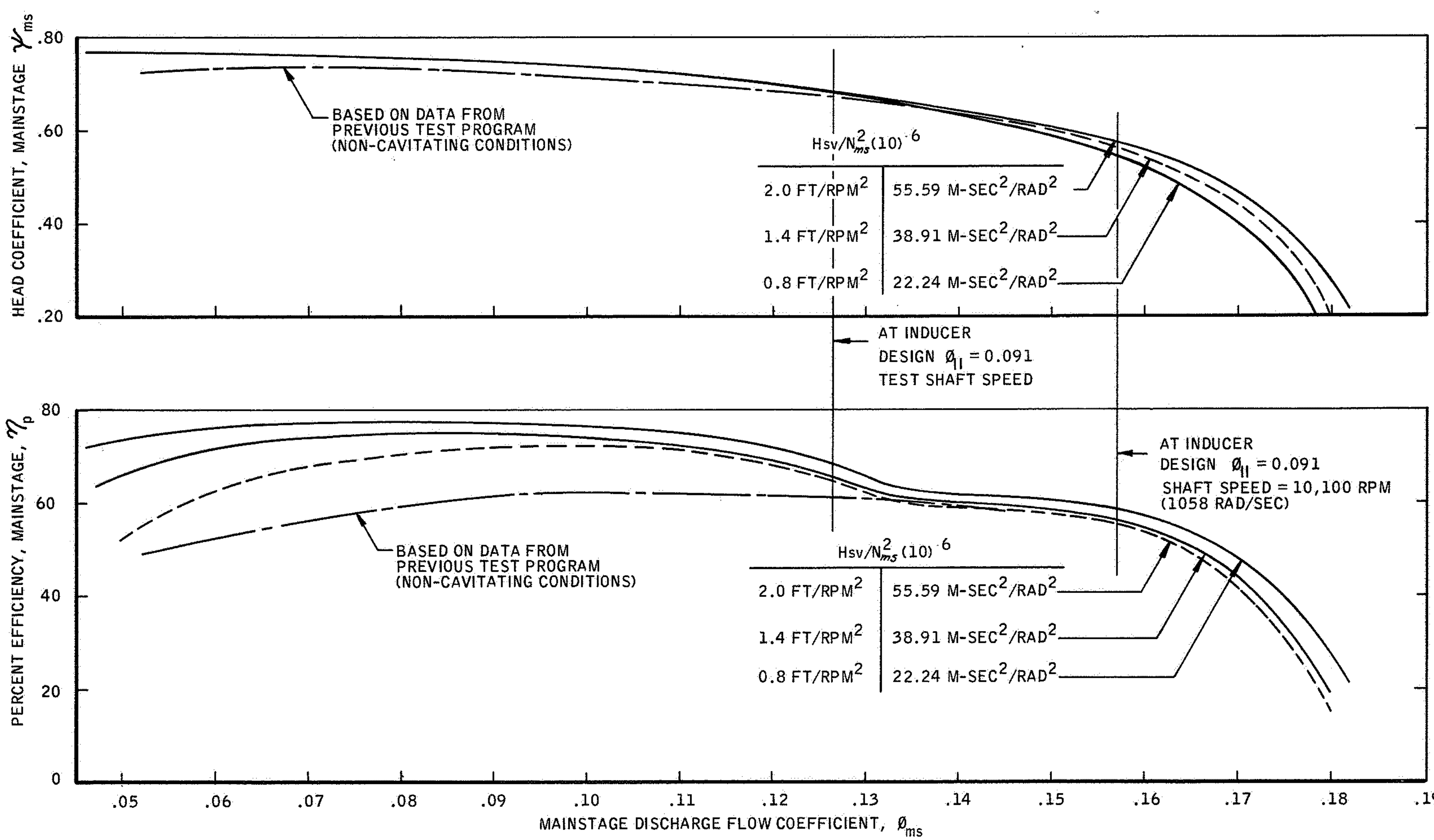


Figure 22. - Efficiency and Head Coefficient vs Flow Coefficient, Main-Stage Pump Performance.

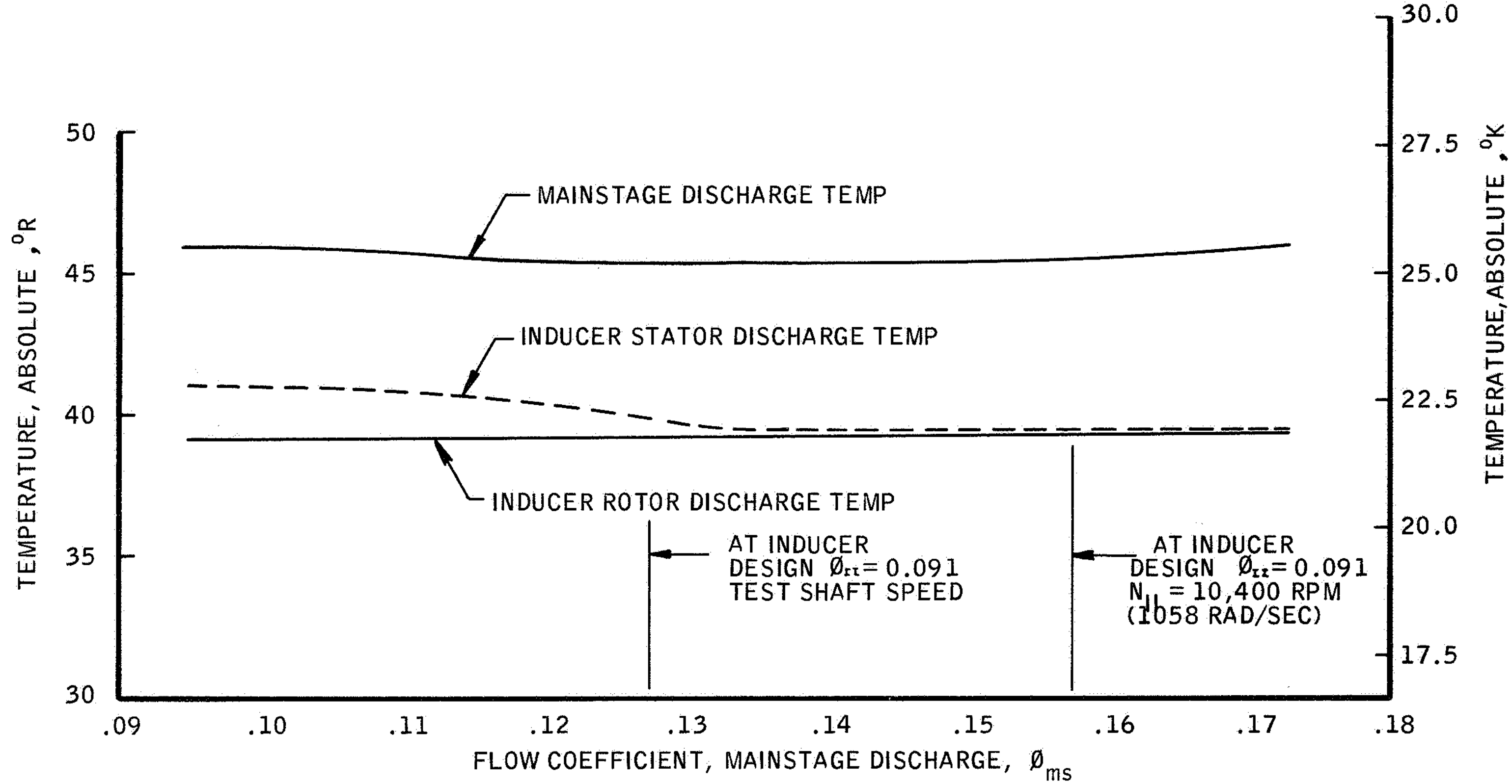


Figure 23. - Temperature vs Flow Coefficient, Test No. 1261-D01-OP-007.

The suction characteristics of the main stage are shown on Figures No. 24 through No. 27 as plots of head coefficient and head loss as a function of Net Positive Suction Head (NPSH) entering into the main-stage pump. Performance is similar to that obtained previously (Ref. 9) with initial loss in head occurring at approximately 10 psi to 20 psi NPSP, depending upon the flow coefficient.

2. Low-Speed Inducer Stage

Head coefficient and efficiency data as a function of flow coefficient are illustrated on Figures No. 28 and No. 29, respectively. The accuracy of the data presented should be noted because of the magnitude of the measurements taken and the difference in measurements that are calculated. The suction pressure error at 3σ is $\pm$ 0.25 psi (0.172 newton/cm^2) and the discharge to the stator at 3σ is $\pm$ 0.5 psi (0.344 newton/cm^2). The temperature measurement at 3σ is $\pm$ 0.17°R (0.0945°K). Figure No. 28 indicates that the head coefficient obtained was within predictions; however, the efficiency shown on Figure No. 29 was not. Again, it appears that the previously mentioned (main-stage discussion) inaccuracy of the interstage instrumentation is the cause. Use of the inducer rotor discharge temperature rather than the stator discharge temperature results in a non-cavitating efficiency value at the design flow coefficiency (0.091), of 74% which better correlates with the design predictions although it is 18 points higher than predicted. An accurate estimate of stage efficiency is not possible with the instrumentation used. It would be difficult in any case with staging of this type in liquid hydrogen.

Stall of the inducer stage occurred at a flow coefficient of approximately 0.062 as indicated by the lower values of the data points to the left of this value on Figure No. 28. The inflection shown in the predicted curves corresponds to a characteristic obtained from a more lightly-loaded rotor stalling at approximately the same point. The higher loading of the stator and rotor in the current application could be expected to give a sharper drop or "step." In this case, the stator stall would be expected to cause the step.

Figures No. 30 through No. 46 show head coefficient versus NPSH in the run tank as well as the vapor content once saturation conditions were reached. The vapor content of the fluid (hydrogen) was calculated assuming an isentropic process. The saturation point was taken at the point where the static pressure in the tank becomes lower than the vapor pressure as indicated by the temperature measurement in the tank. This occurs as a result of the difference in the response time of the temperature and pressure transducers. These plots indicate the low-speed stage suffered little or no loss in head from positive $NPSH_{tk}$ to saturation conditions. The loss was less than expected (as indicated on Figures No. 28 and No. 29 for saturated conditions). The test was conducted at a temperature range of from 37.5°R (20.8°K) to 39.5°R (21.9°K). The maximum vapor content achieved was in excess of 40% vapor by mixture volume (see Figure No. 39). At that instant, the main-stage suffered an approximate 6% loss in head.

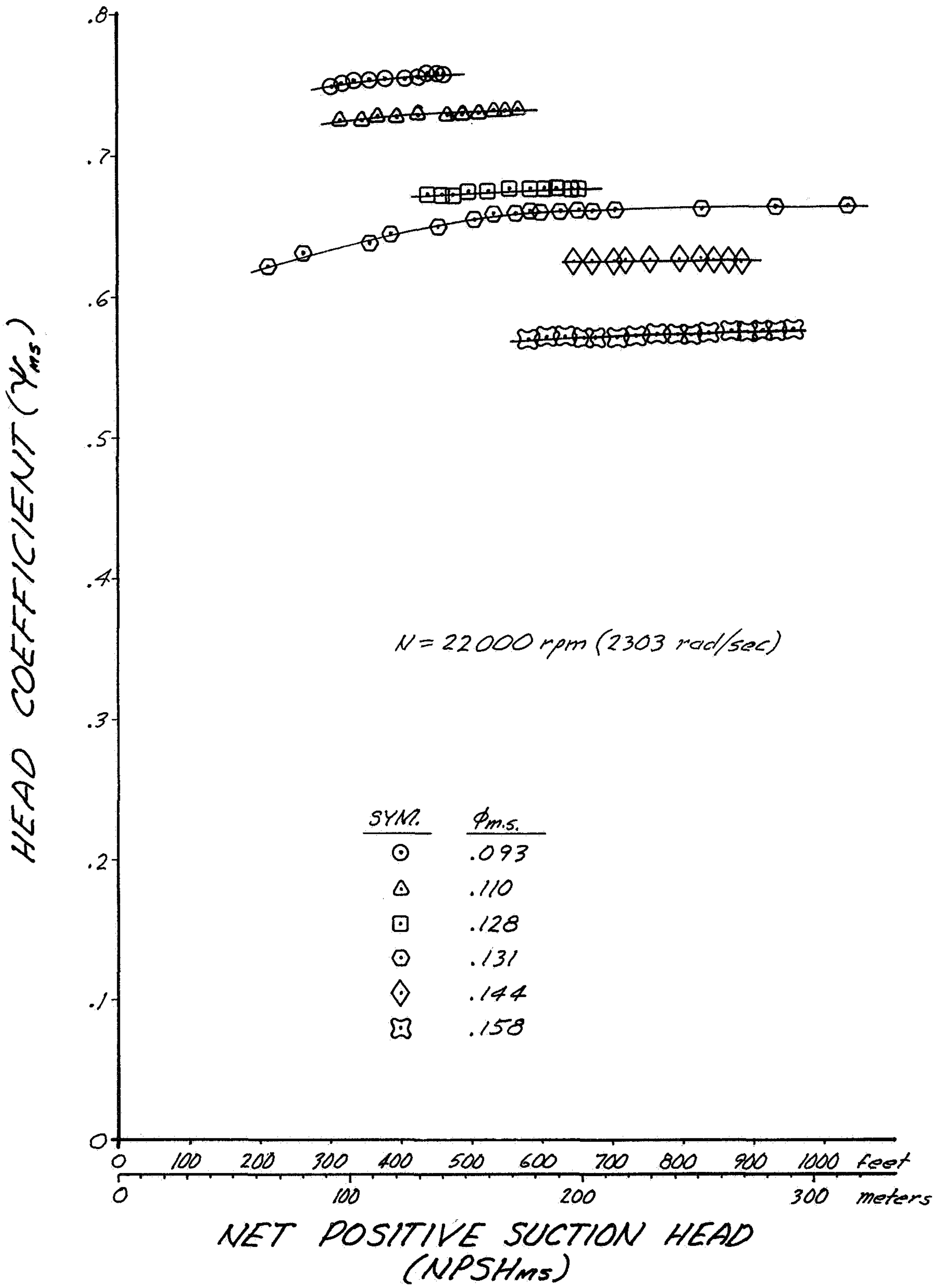


Figure 24. - Main-Stage Performance, ψ vs NPSH (22,000 rpm)

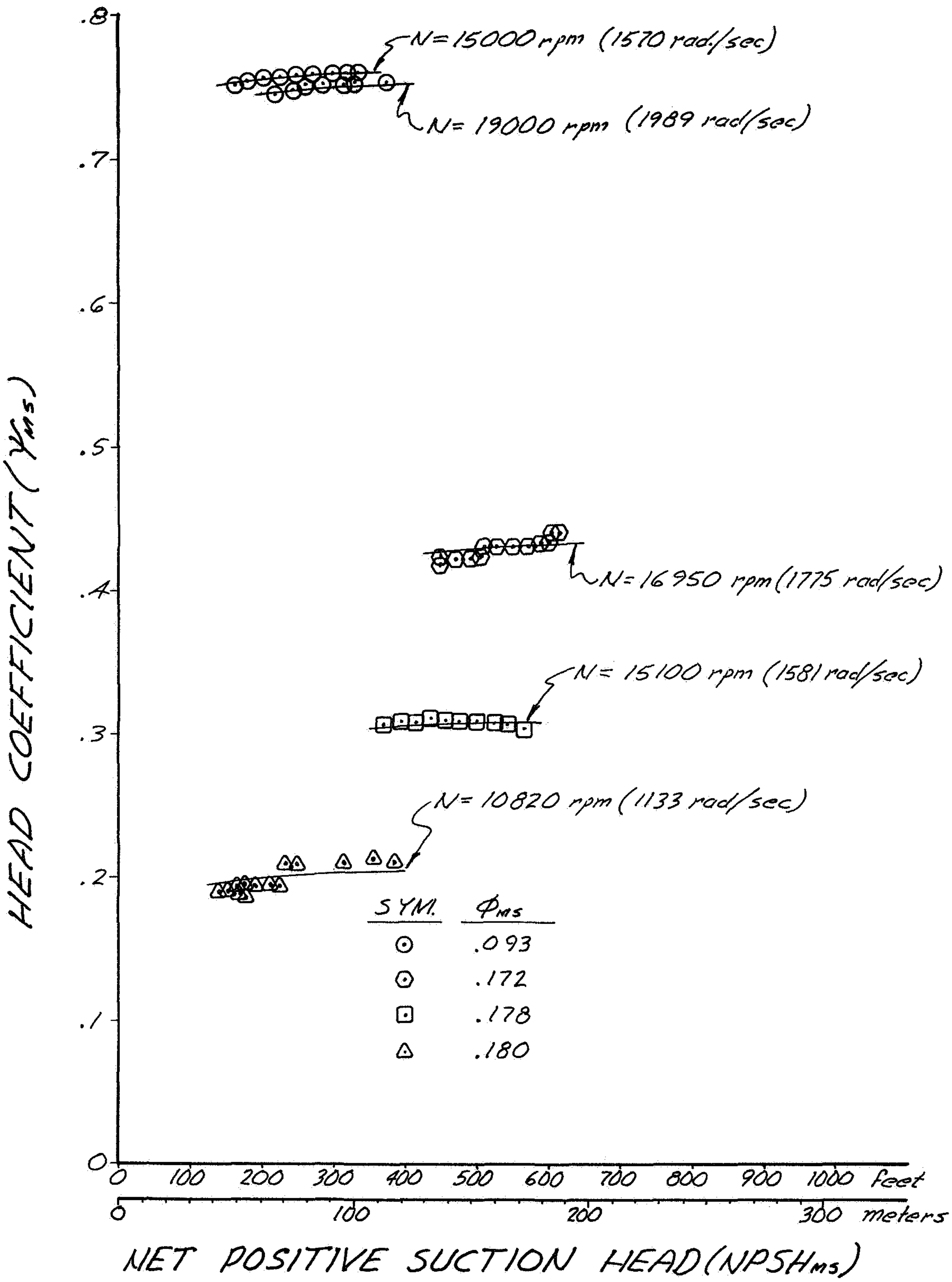


Figure 25. - Main-Stage Performance, ψ vs NPSH (15,000 rpm, 19,000 rpm, 16,950 rpm, 15,100 rpm, and 10,820 rpm).

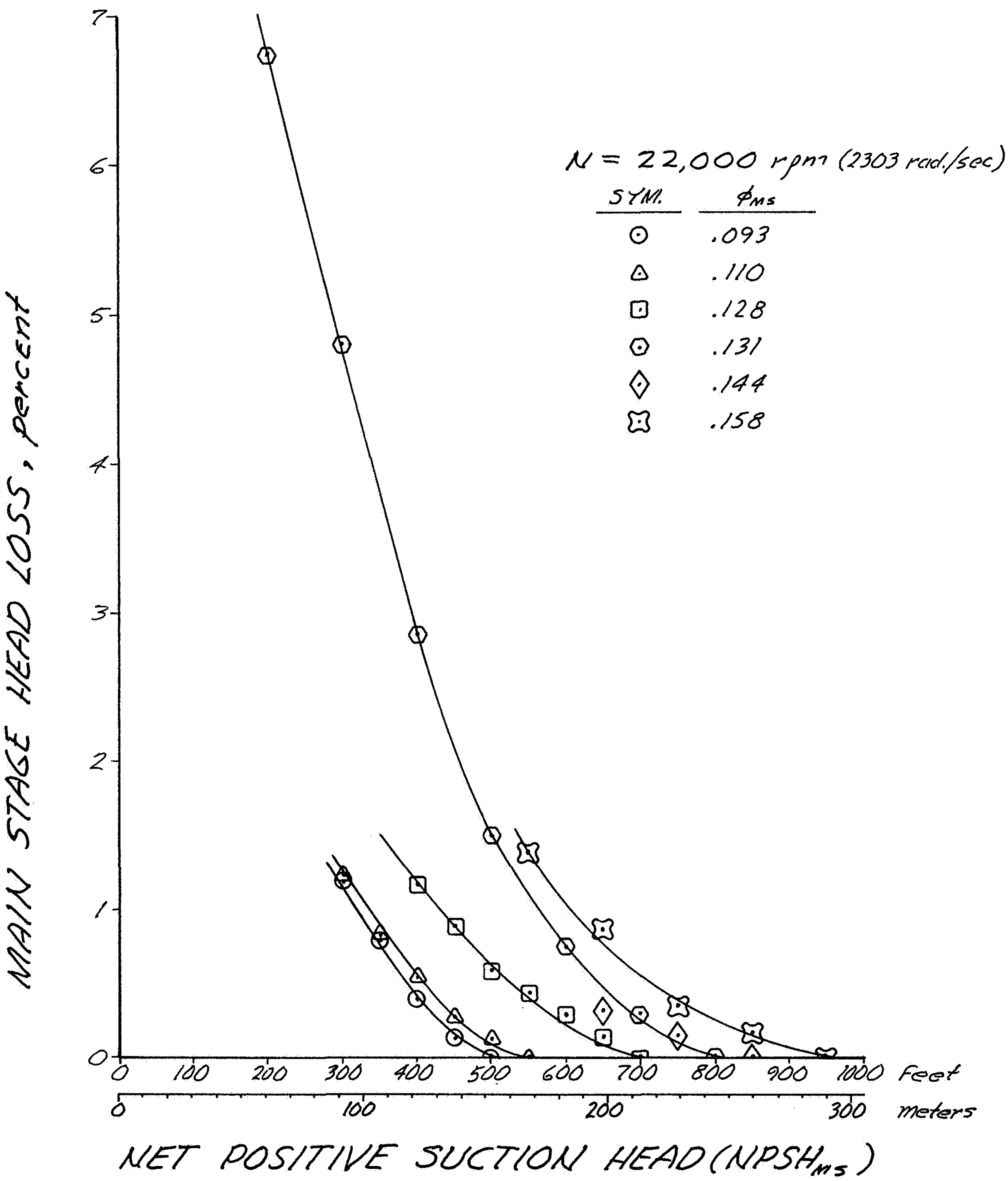


Figure 26. - Main-Stage Performance, Head Loss vs NPSH (22,000 rpm).

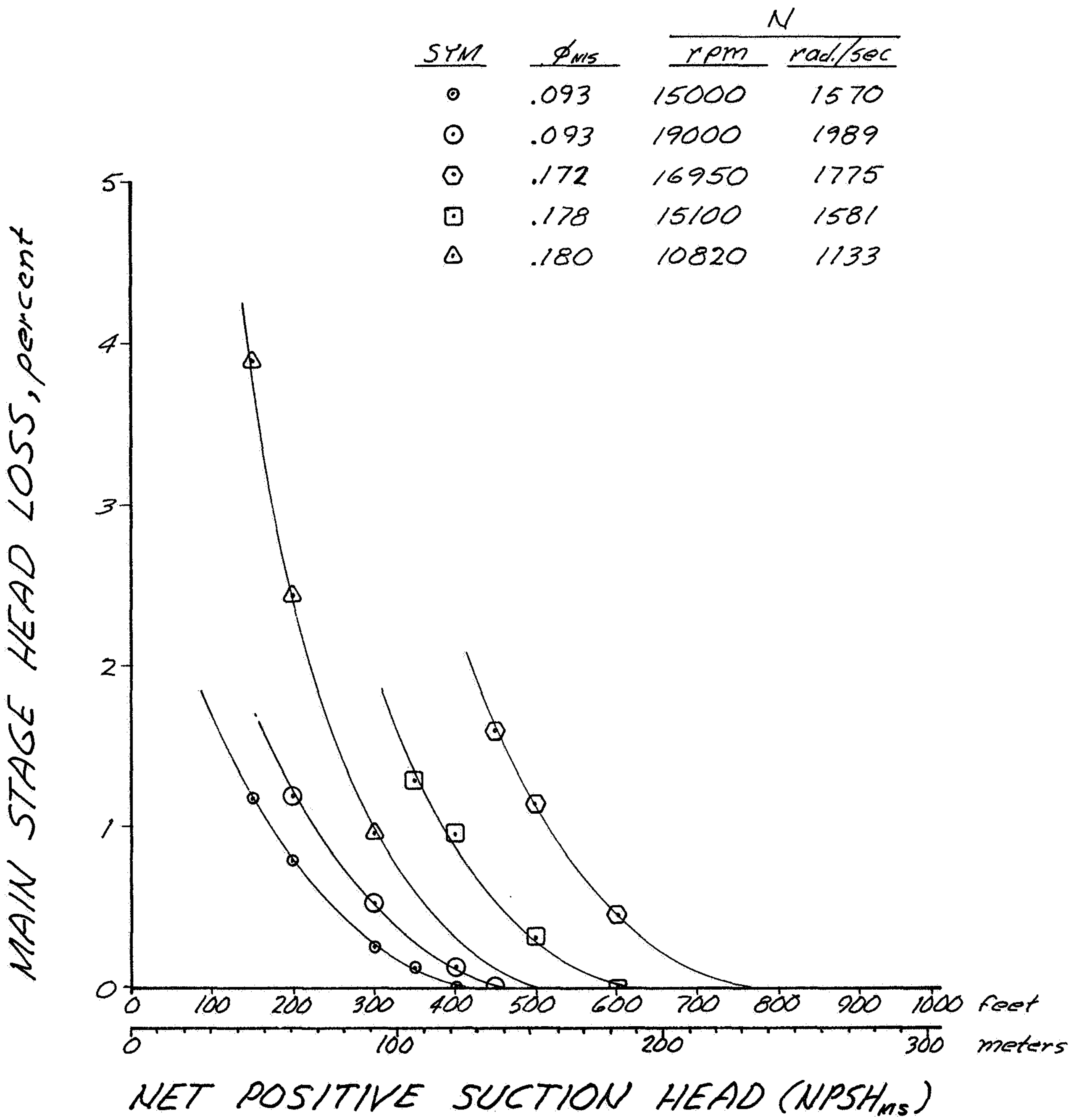


Figure 27. - Main-Stage Performance, Head Loss vs NPSH (15,000 rpm, 19,000 rpm, 16,950 rpm, 15,100 rpm, and 10,820 rpm).

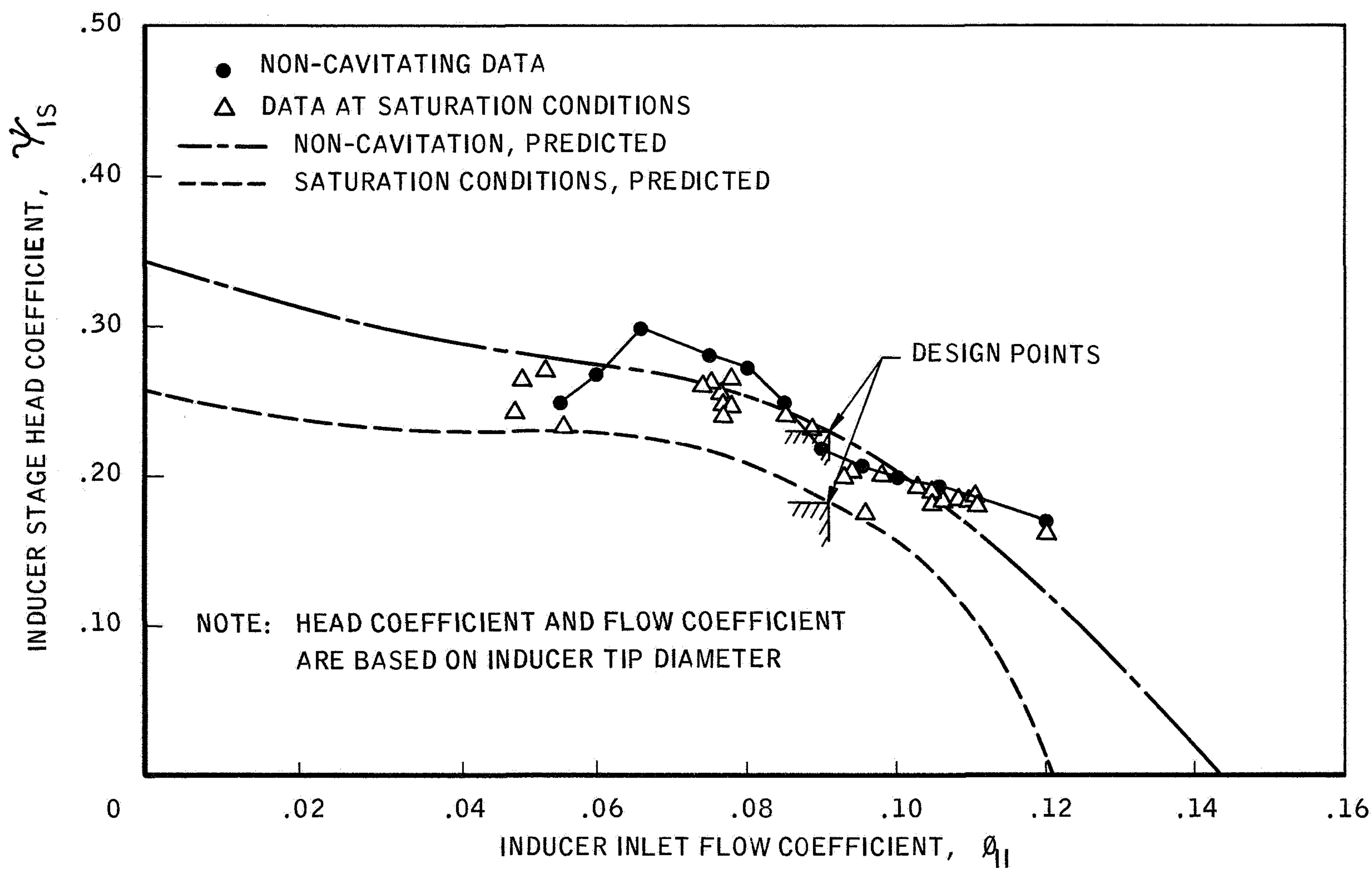


Figure 28. Inducer Stage Performance, Head Coefficient vs Flow Coefficient

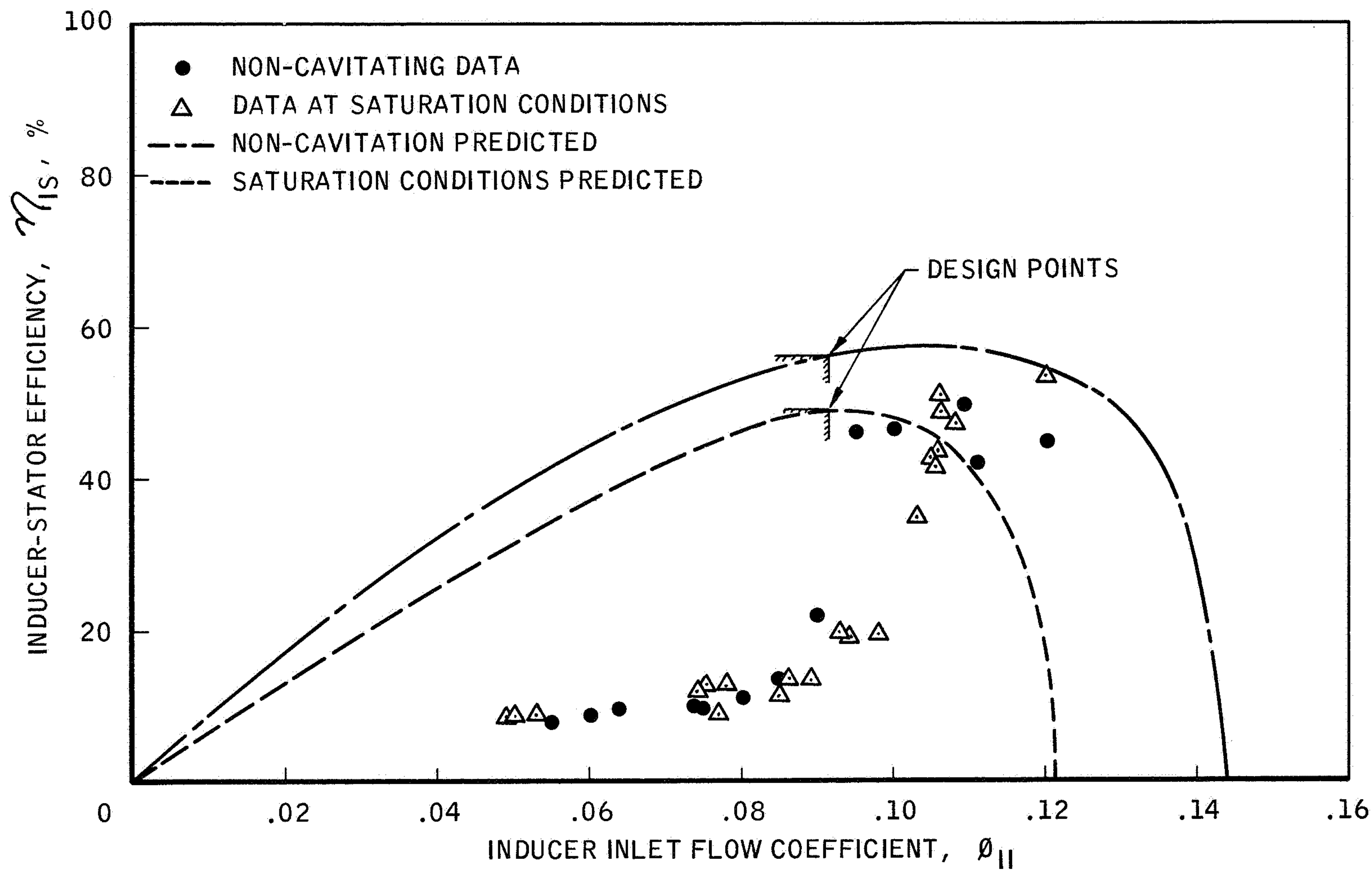


Figure 29. - Inducer Stage Performance, Efficiency vs Flow Coefficient.

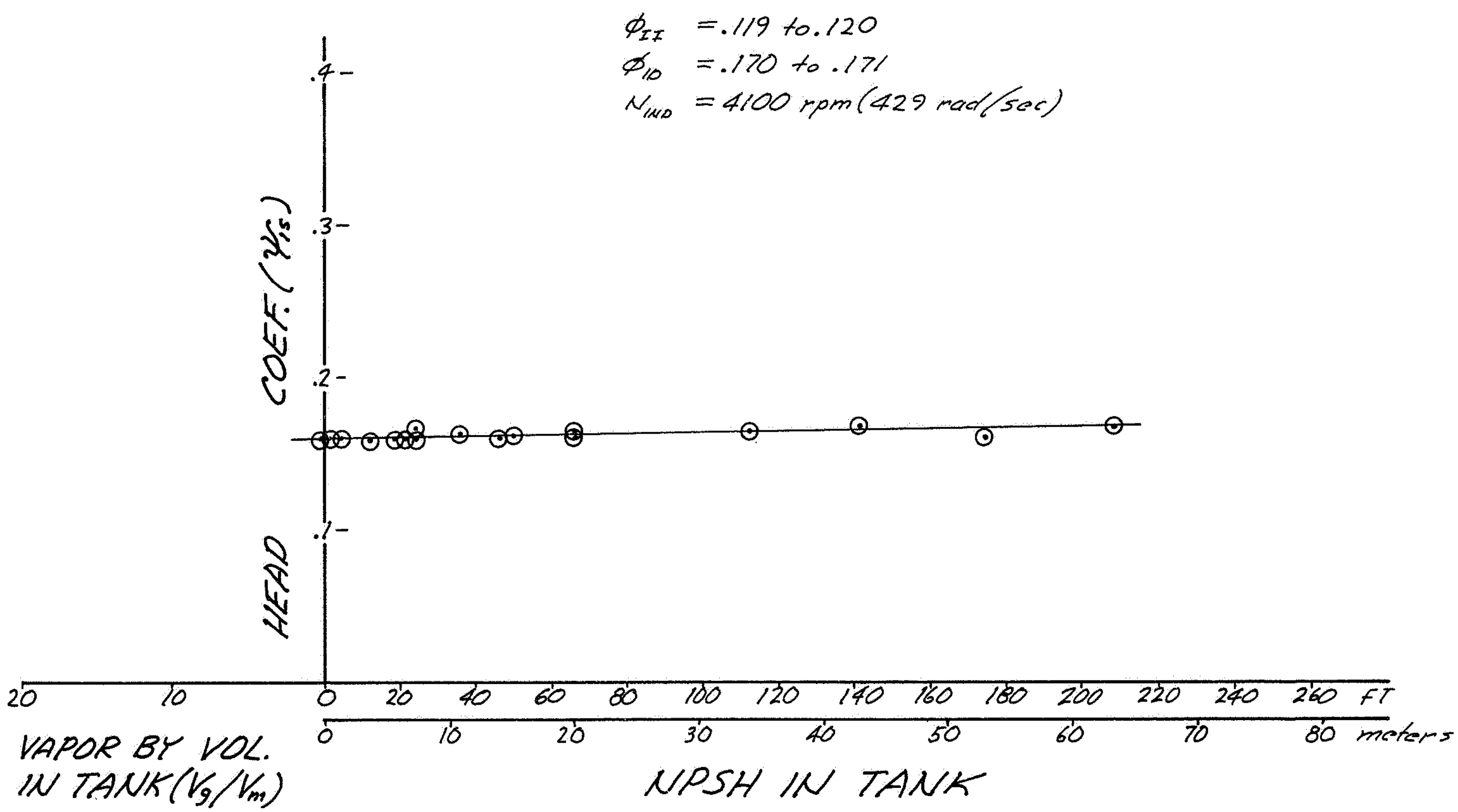


Figure 30. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -007 (4100 rpm).

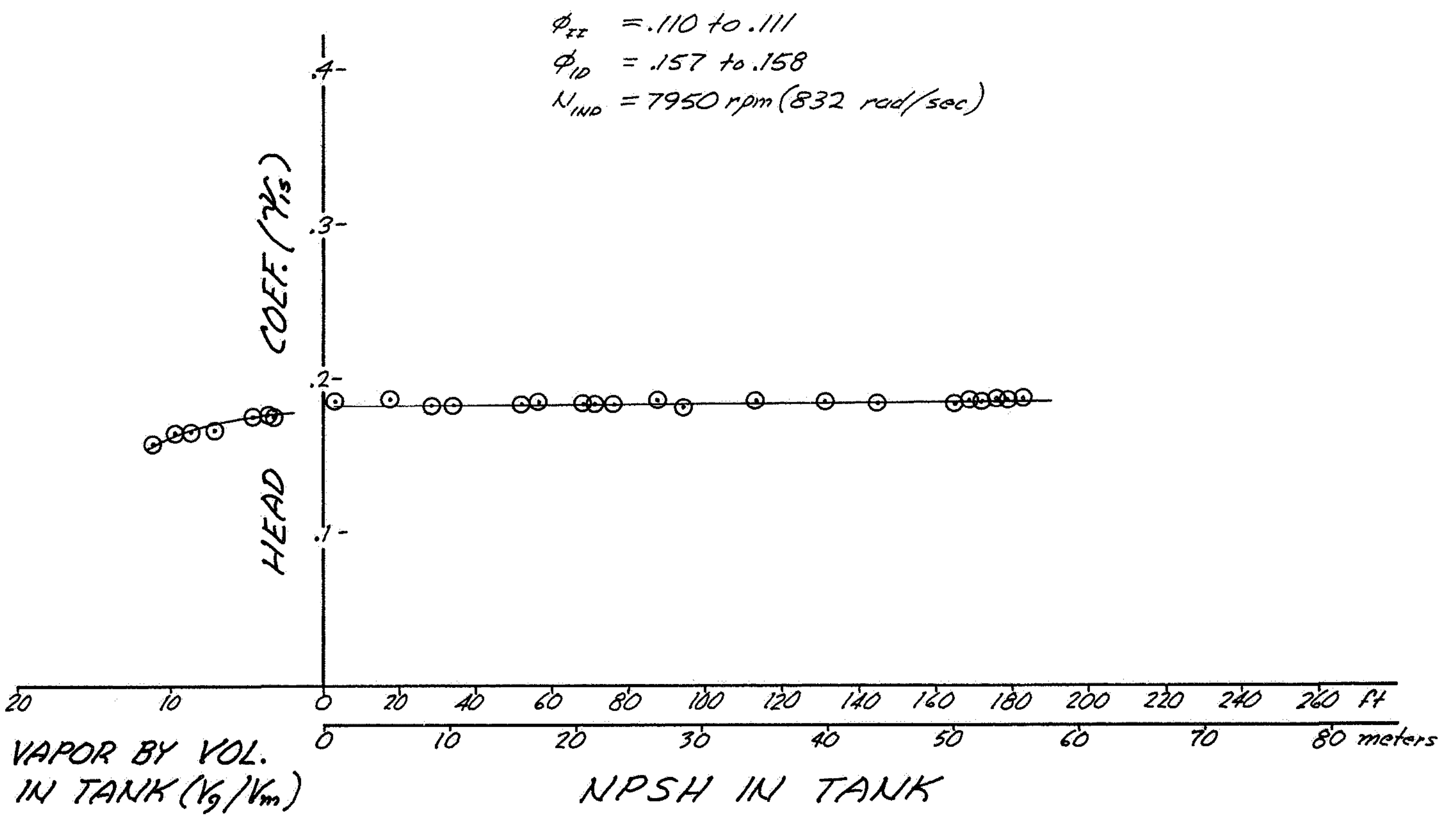


Figure 31. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (7950 rpm).

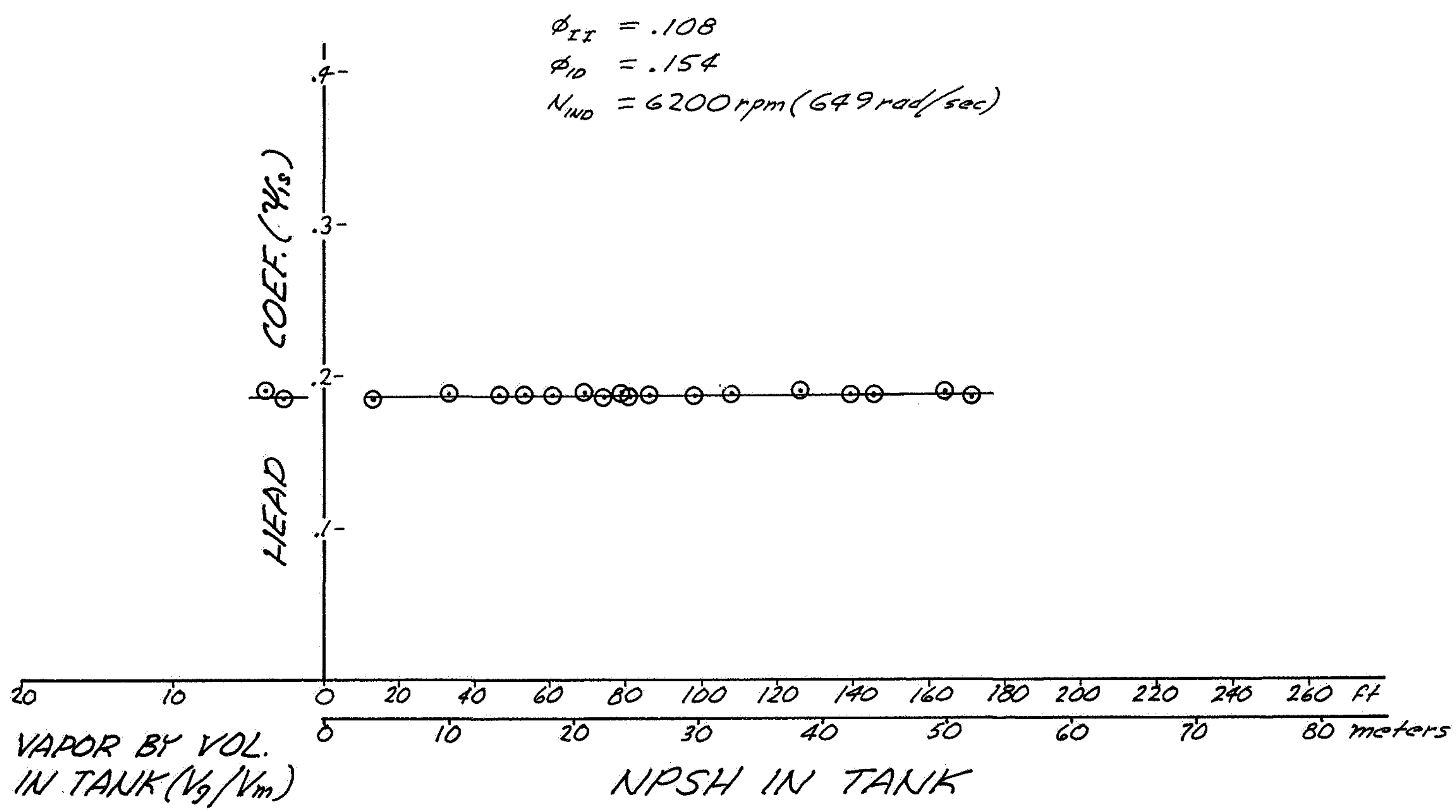


Figure 32. - Inducer Performance, Head Coefficient vs Vapor Volume and NPSH in Tank, Test -007 (6200 rpm).

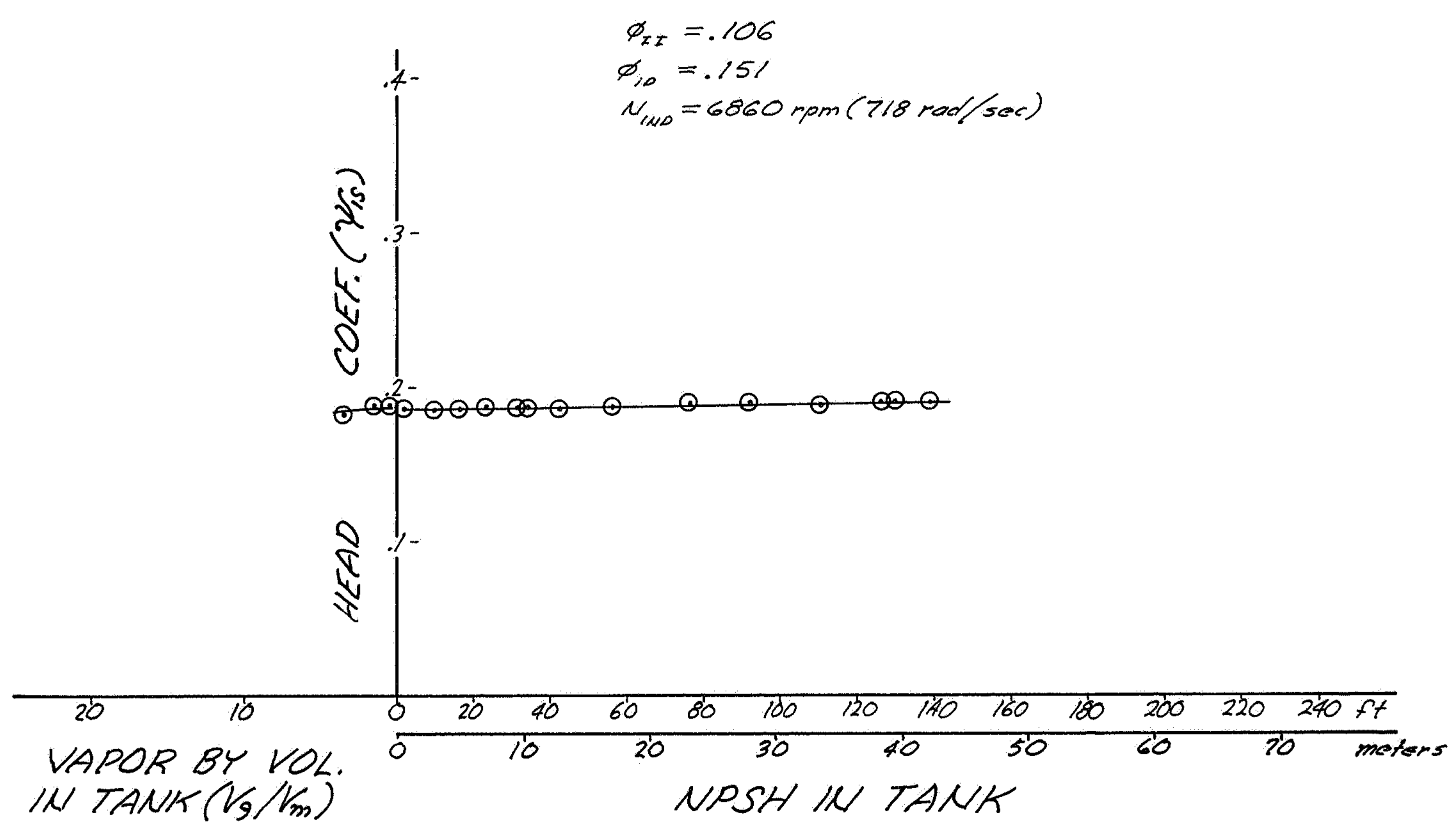


Figure 33. - Inducer Performance, Head Coefficient vs Vapor Volume and NPSH in Tank, Test -007 (6860 rpm).

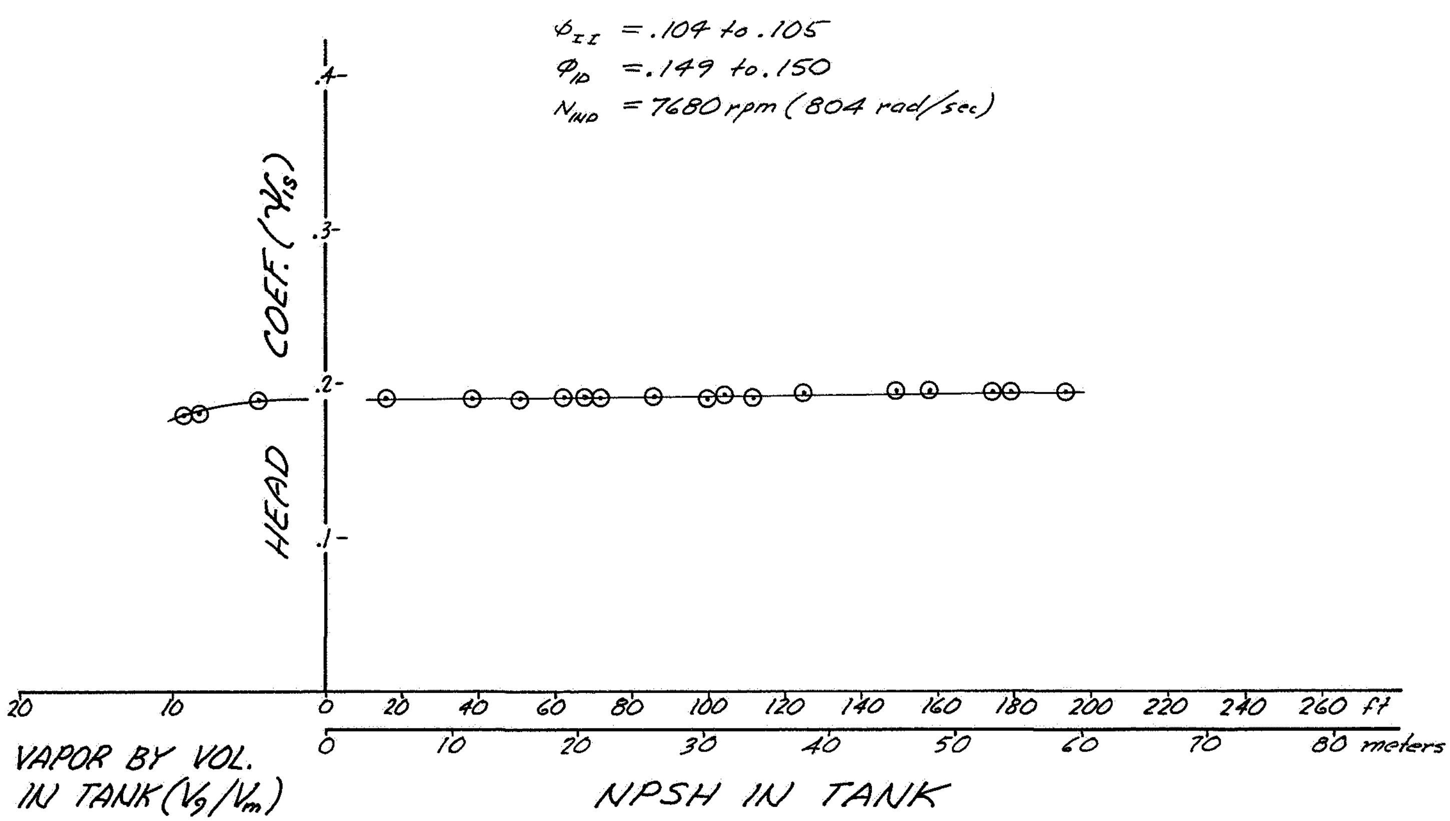


Figure 34. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (7680 rpm).

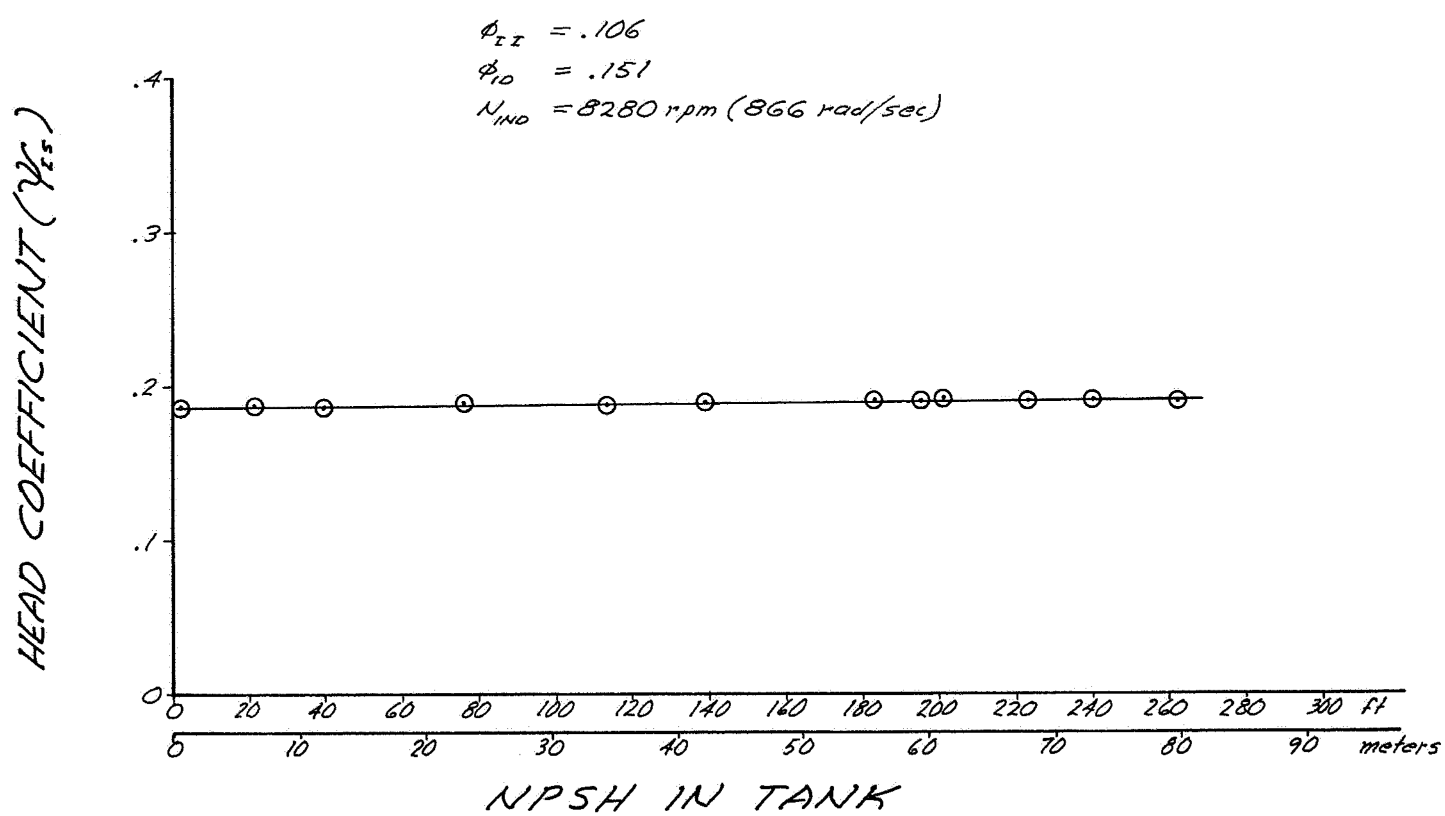


Figure 35. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -005 (8280 rpm).

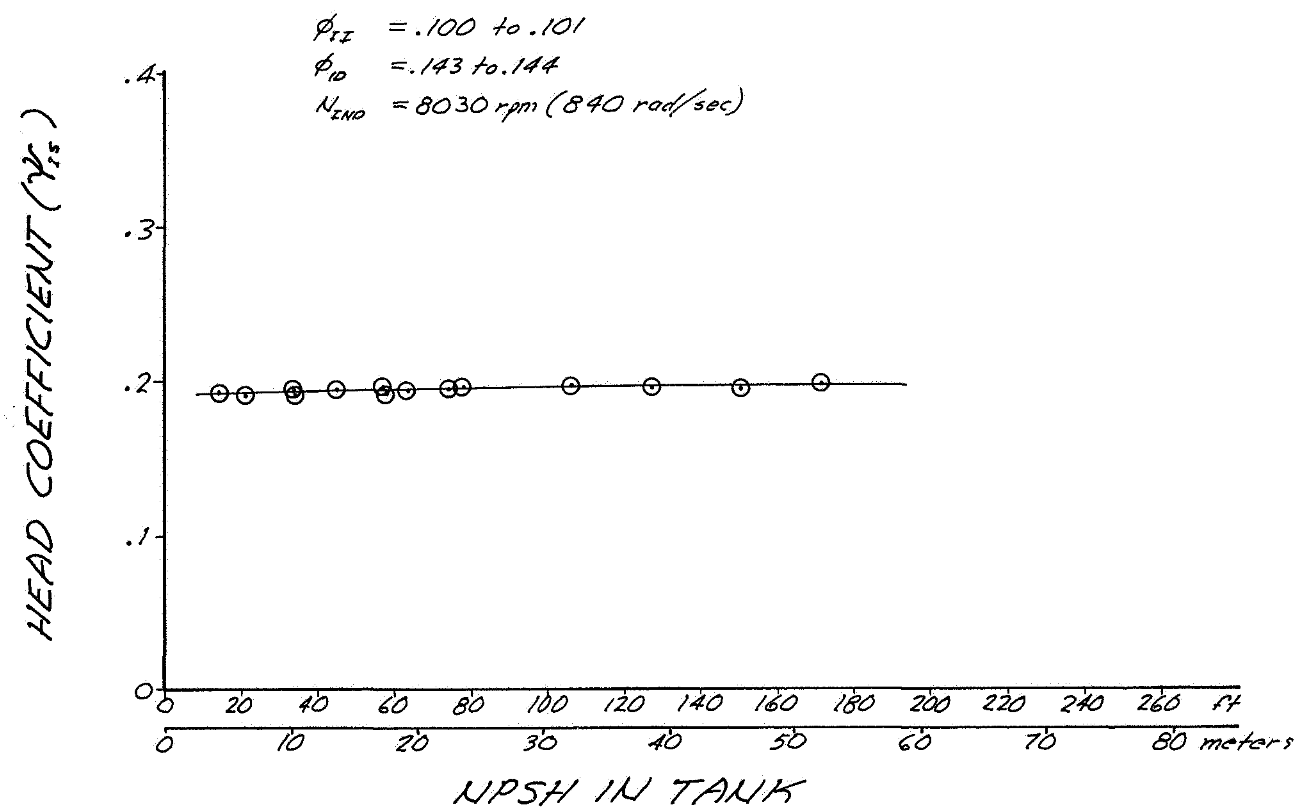


Figure 36. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -005 (8030 rpm).

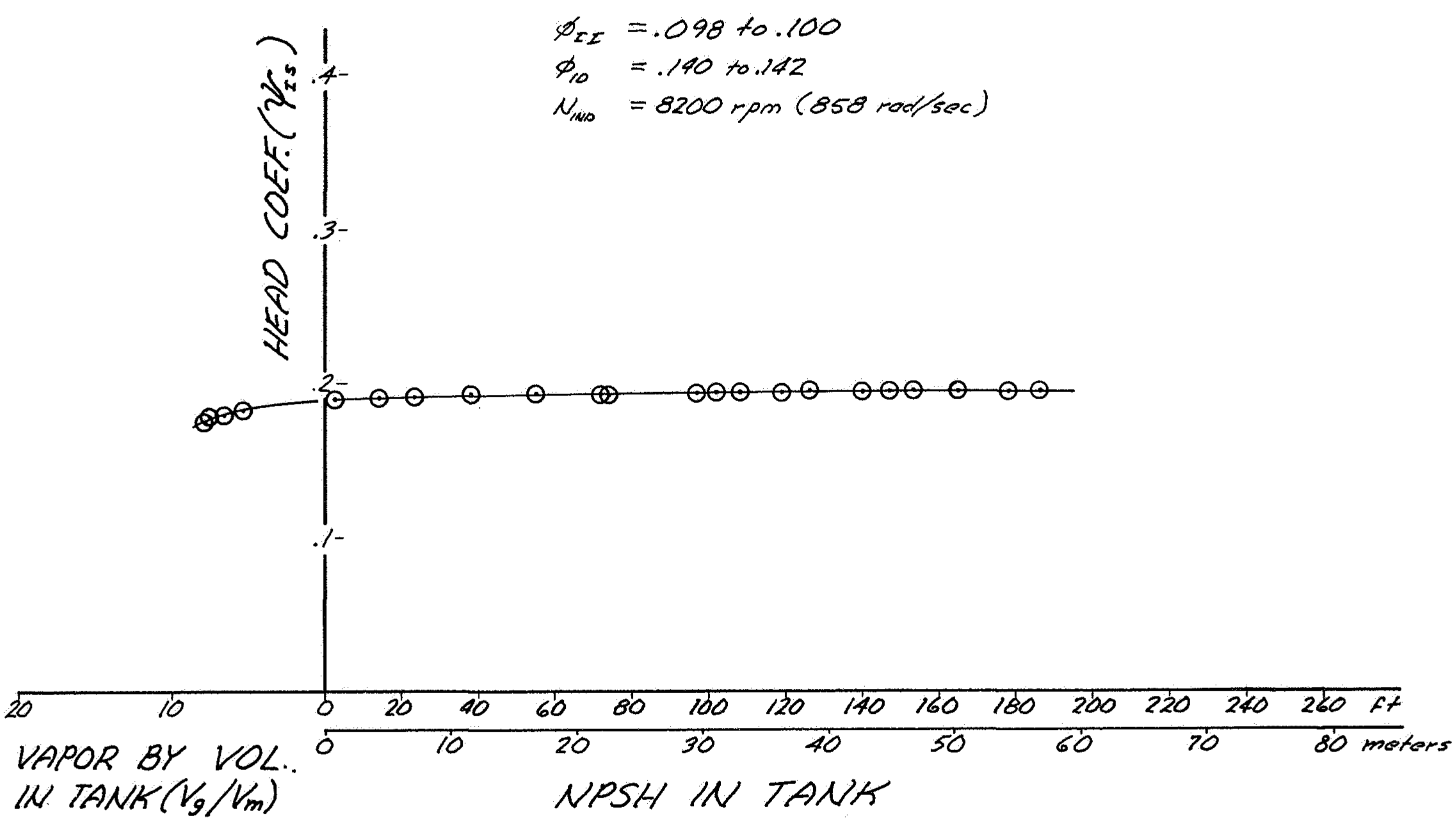


Figure 37. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -004A (8200 rpm).

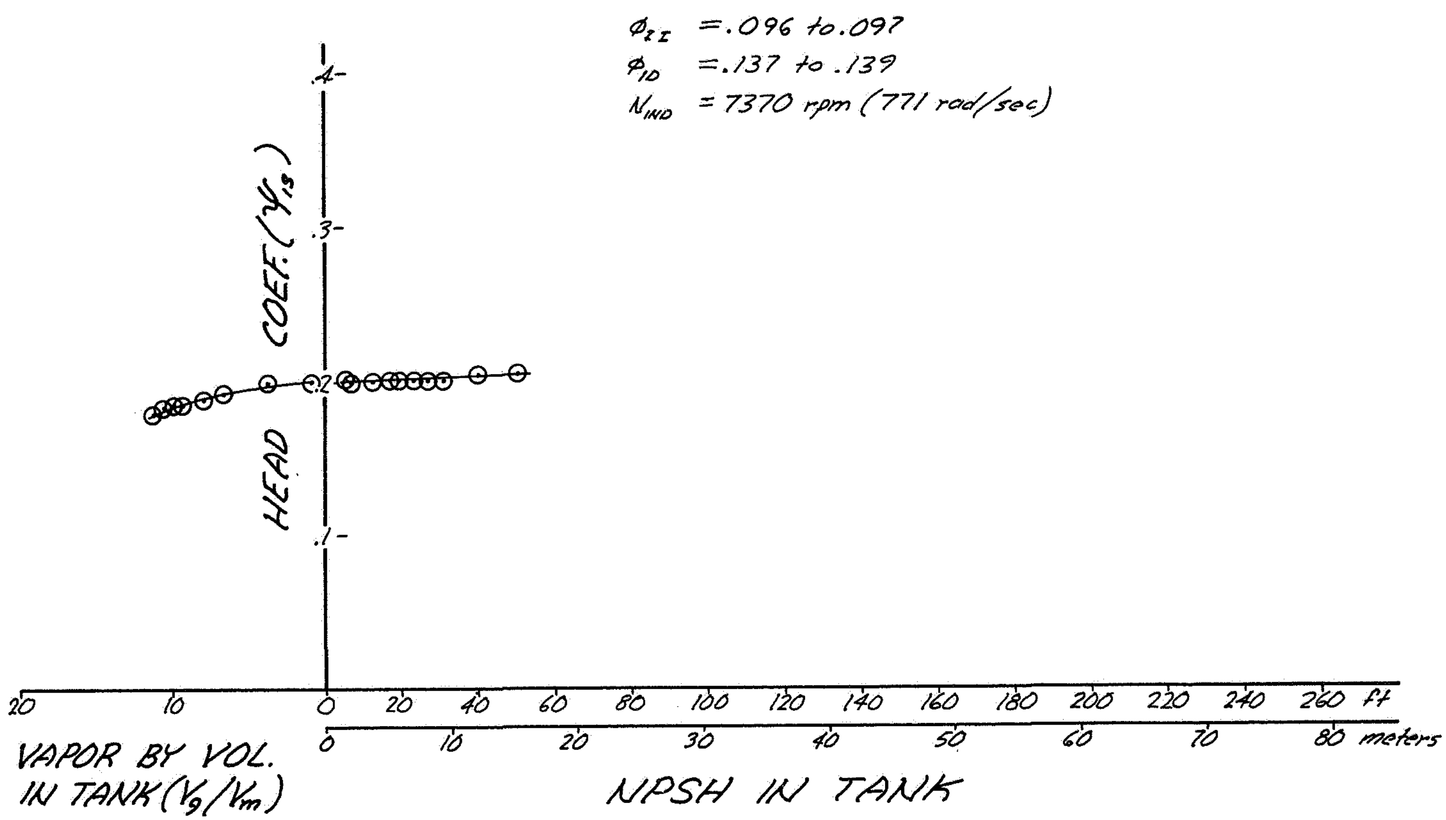


Figure 38. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (7370 rpm).

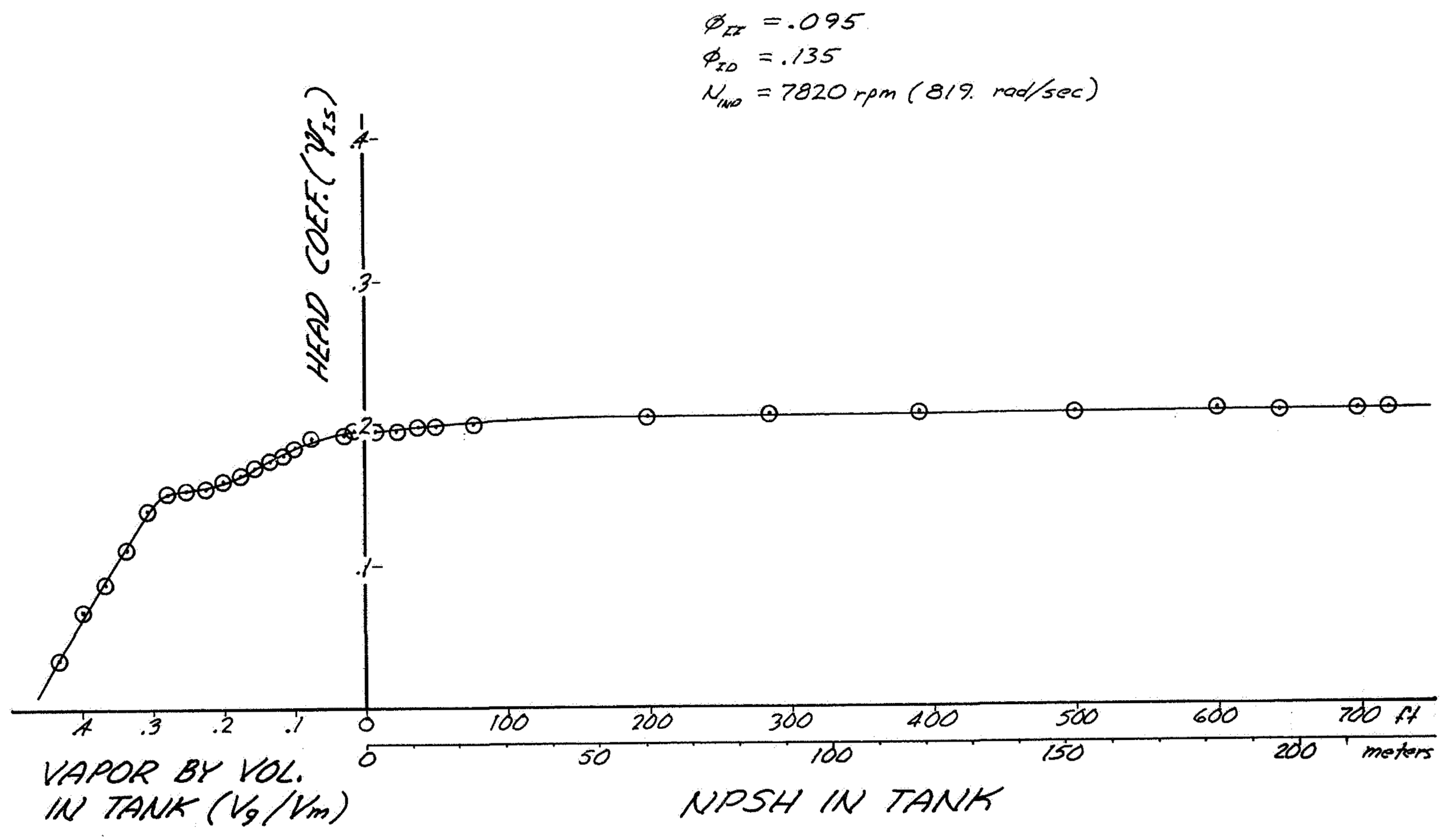


Figure 39. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -003 (7820 rpm).

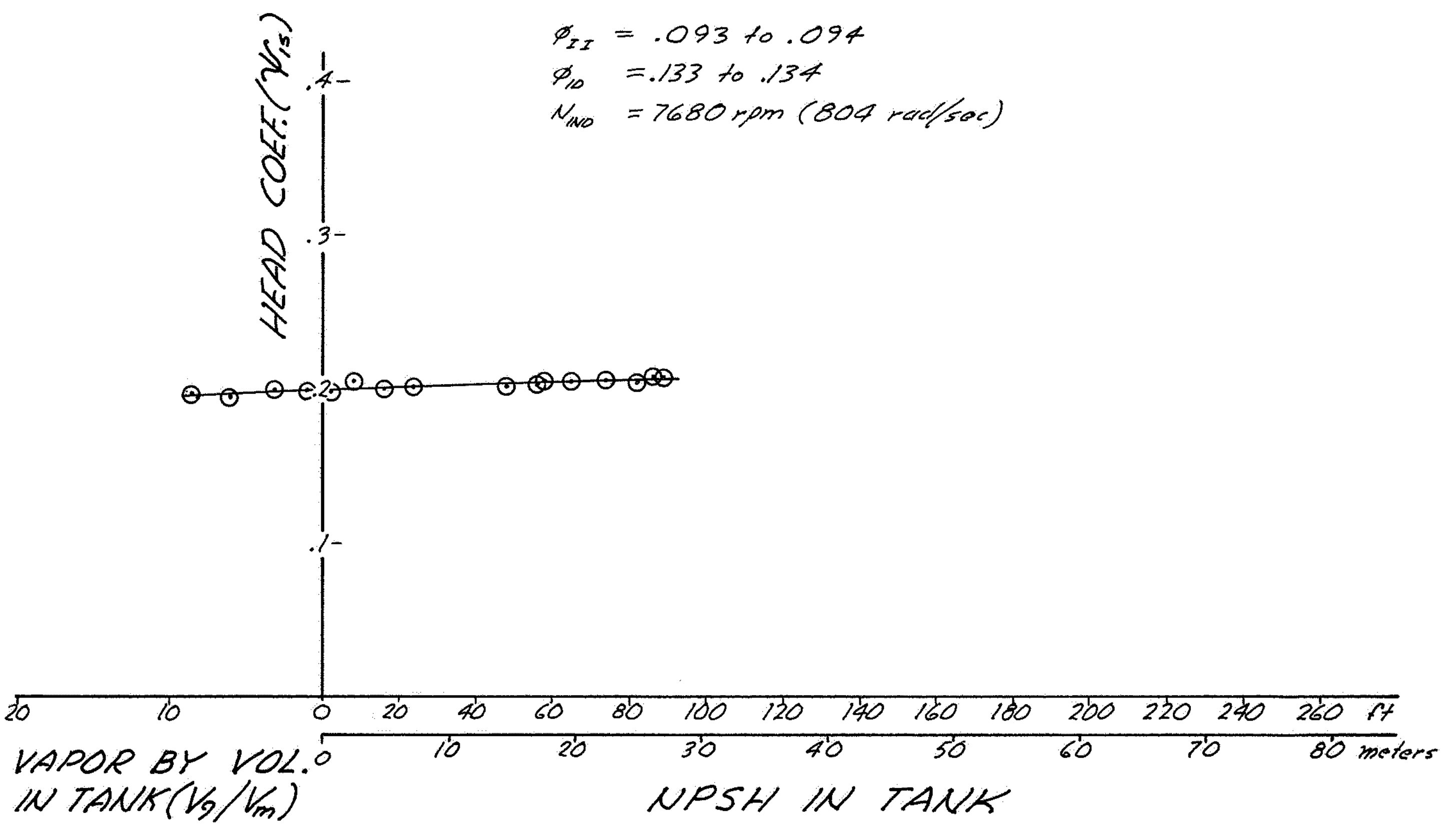


Figure 40. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -005 (7680 rpm).

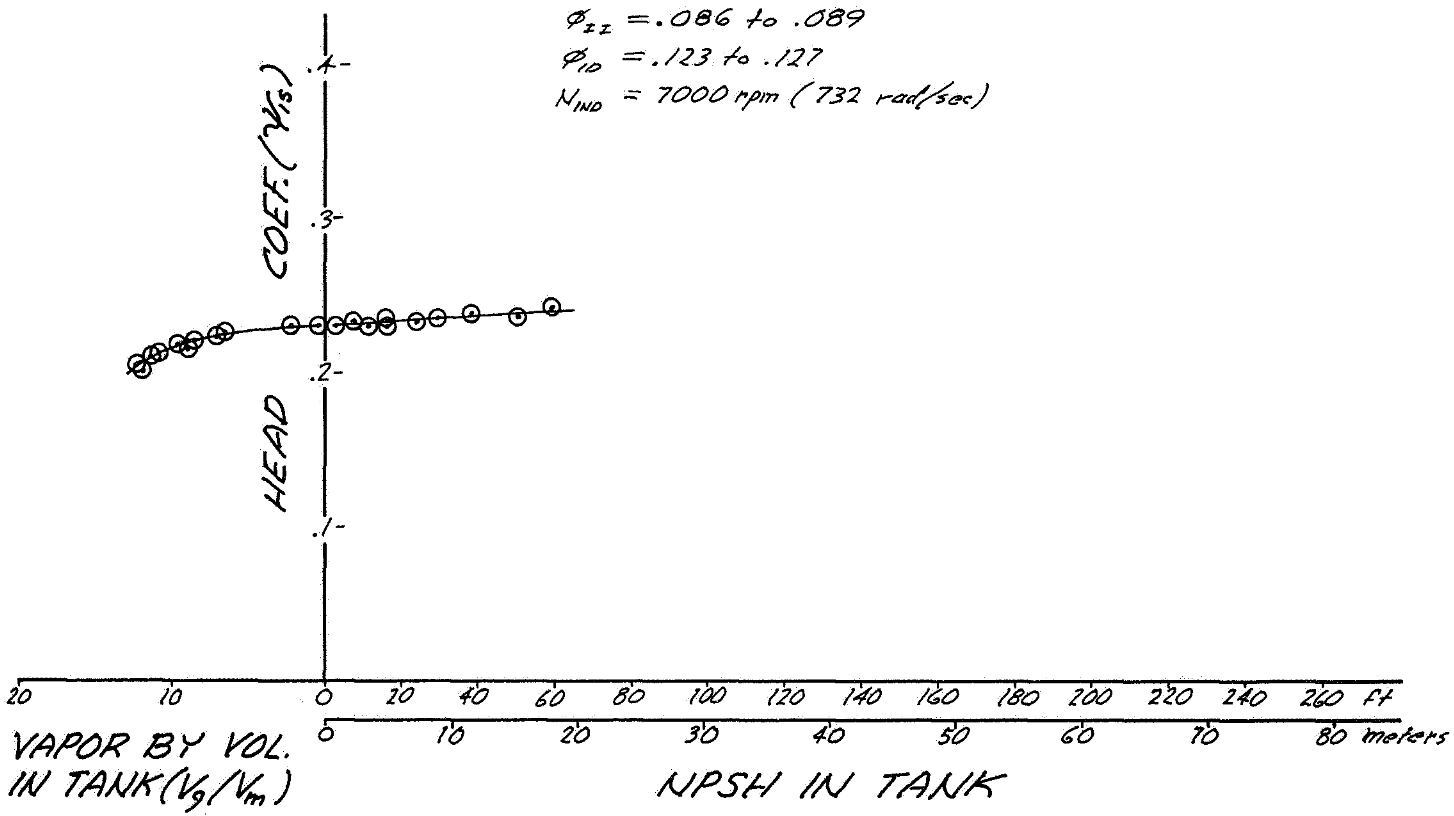


Figure 41. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (7000 rpm).

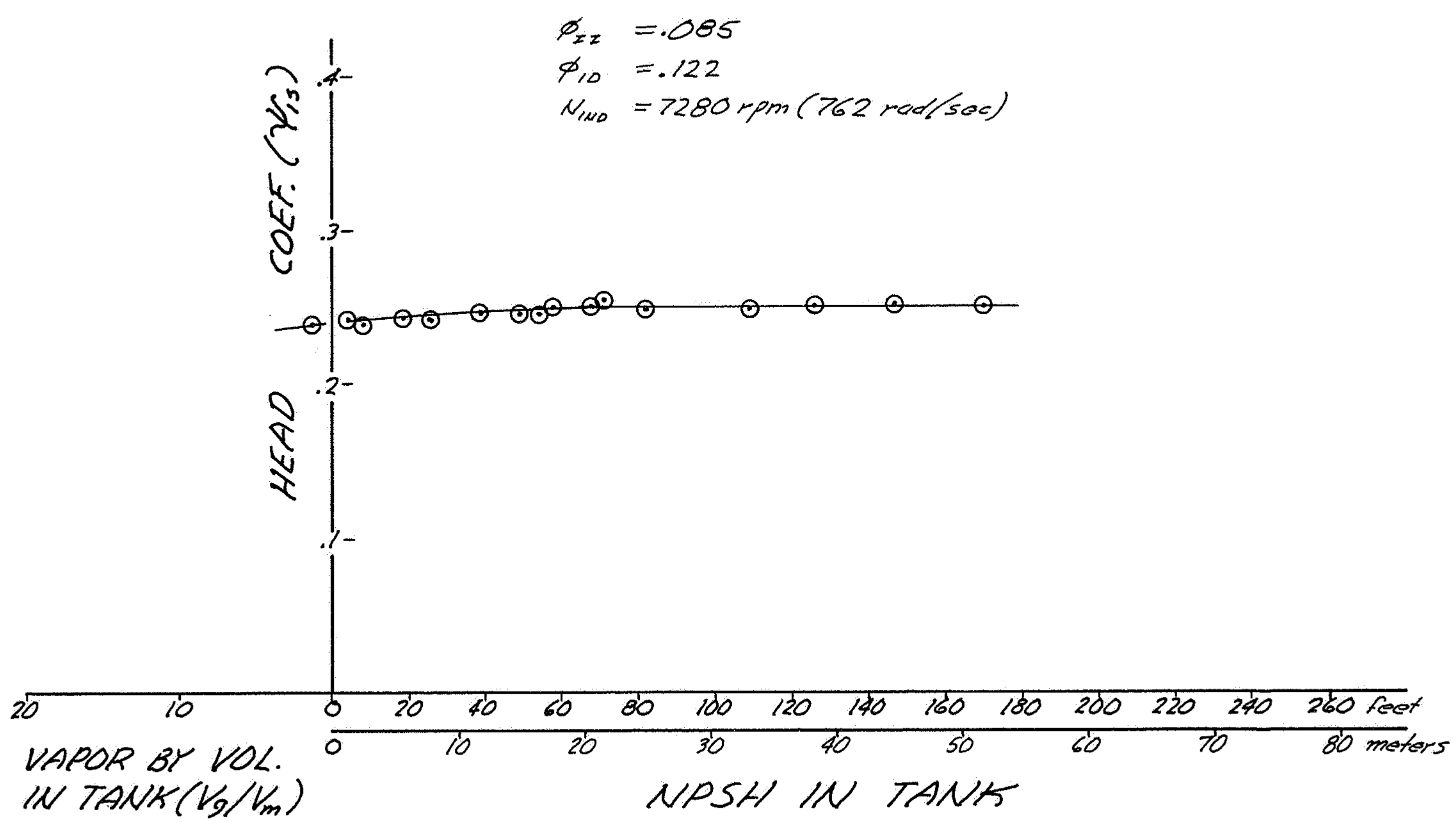


Figure 42. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -005 (7280 rpm).

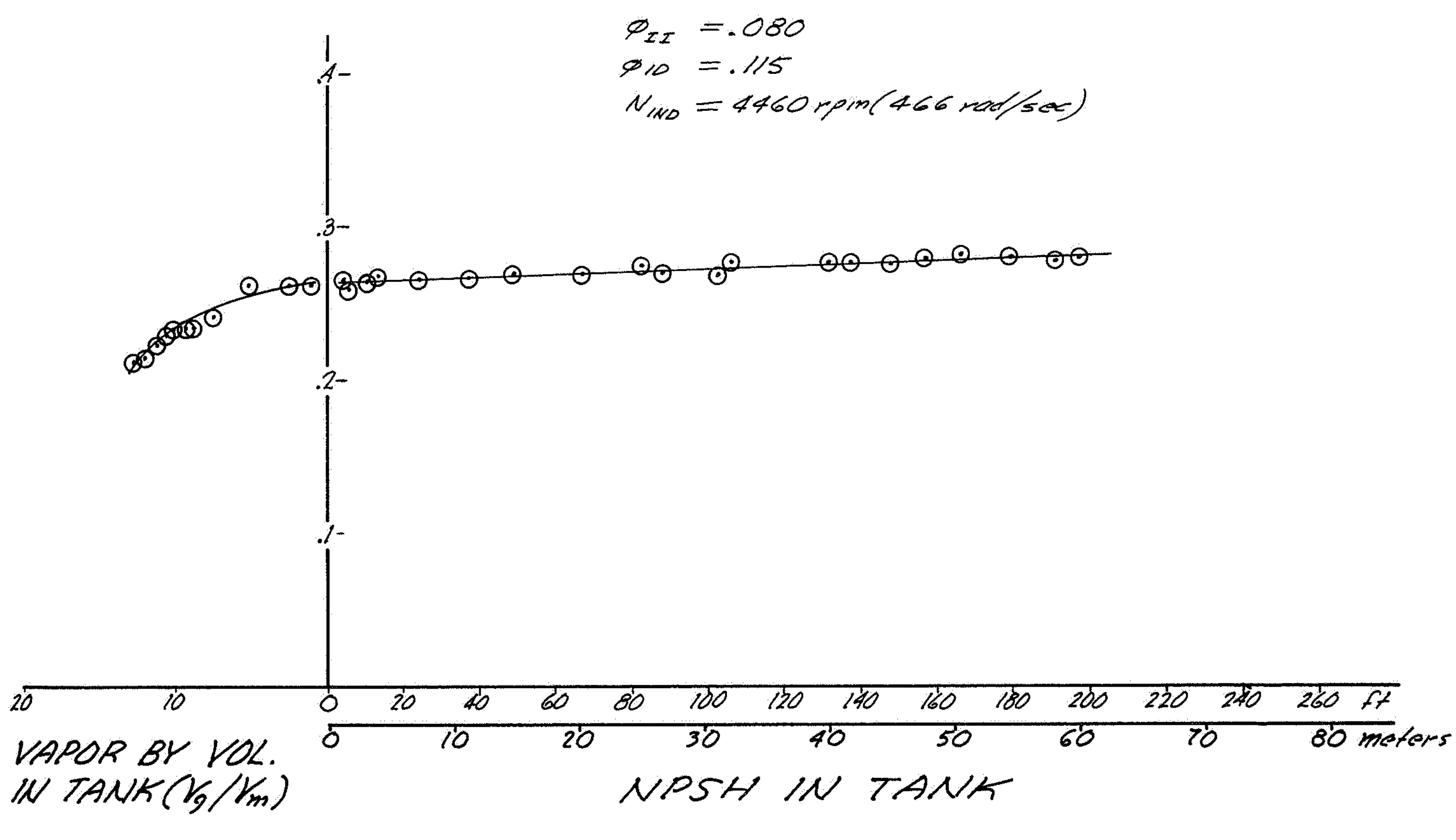


Figure 43. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006, (4460 rpm).

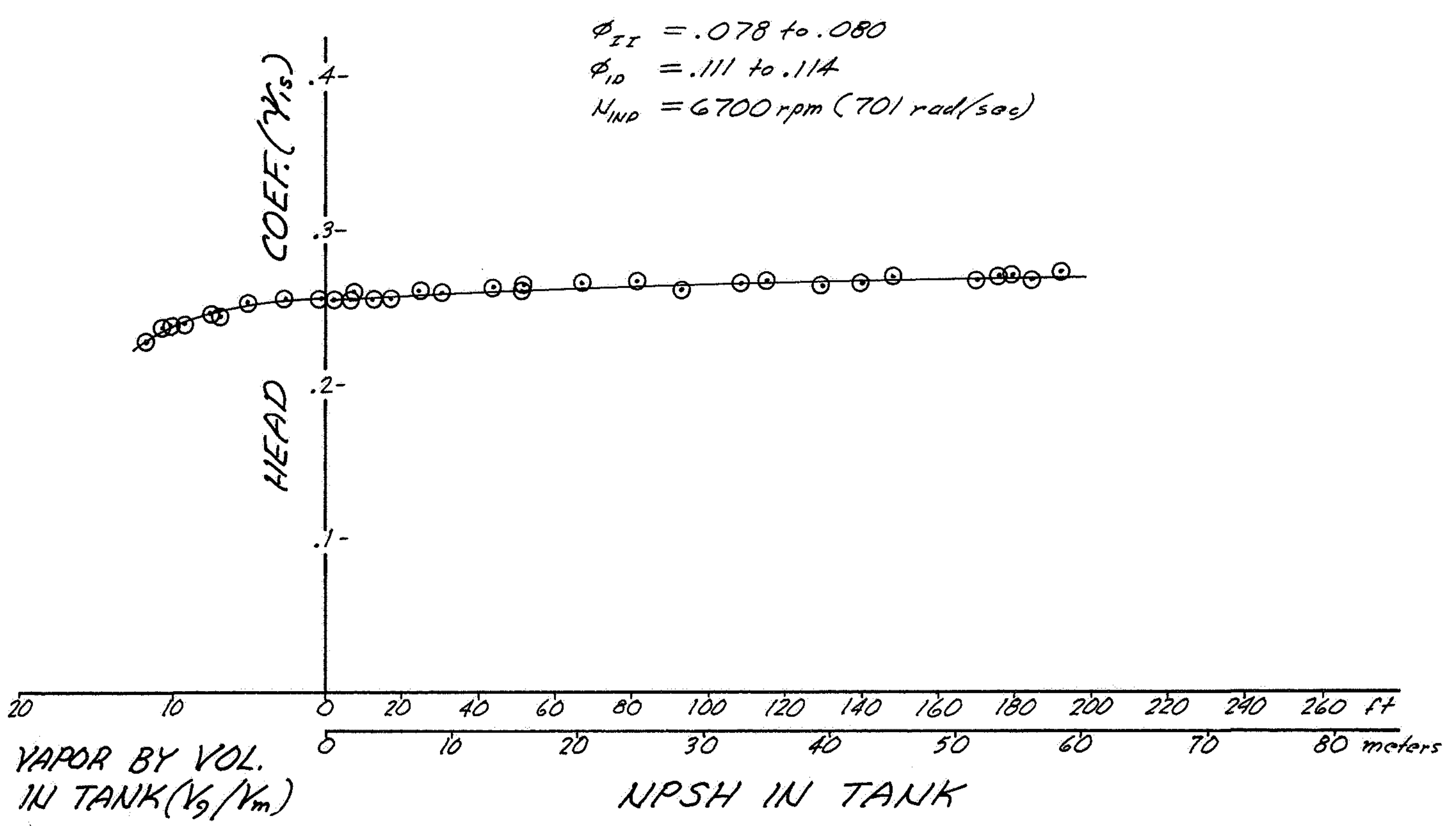


Figure 44. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (6700 rpm).

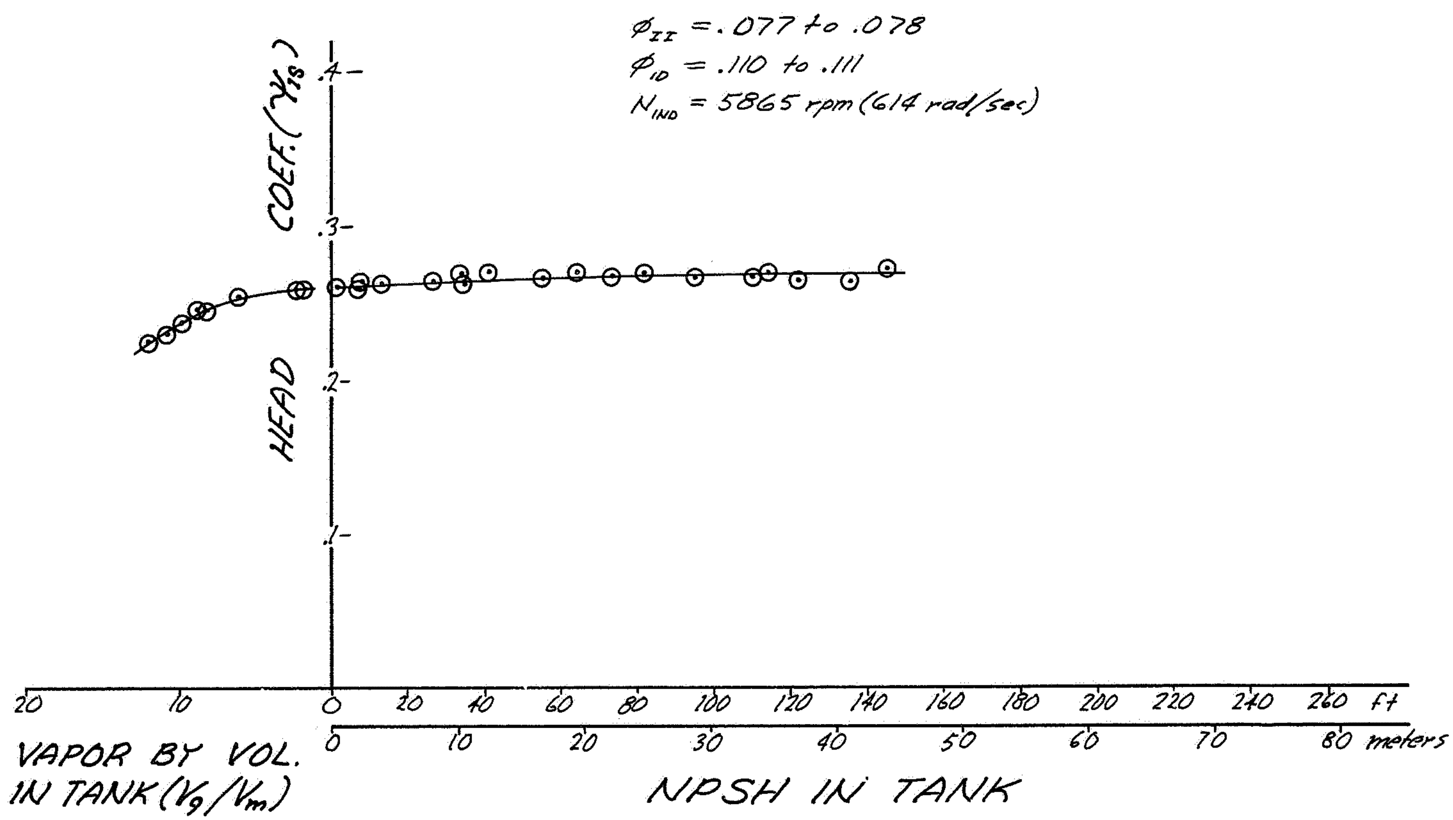


Figure 45. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -006 (5865 rpm).

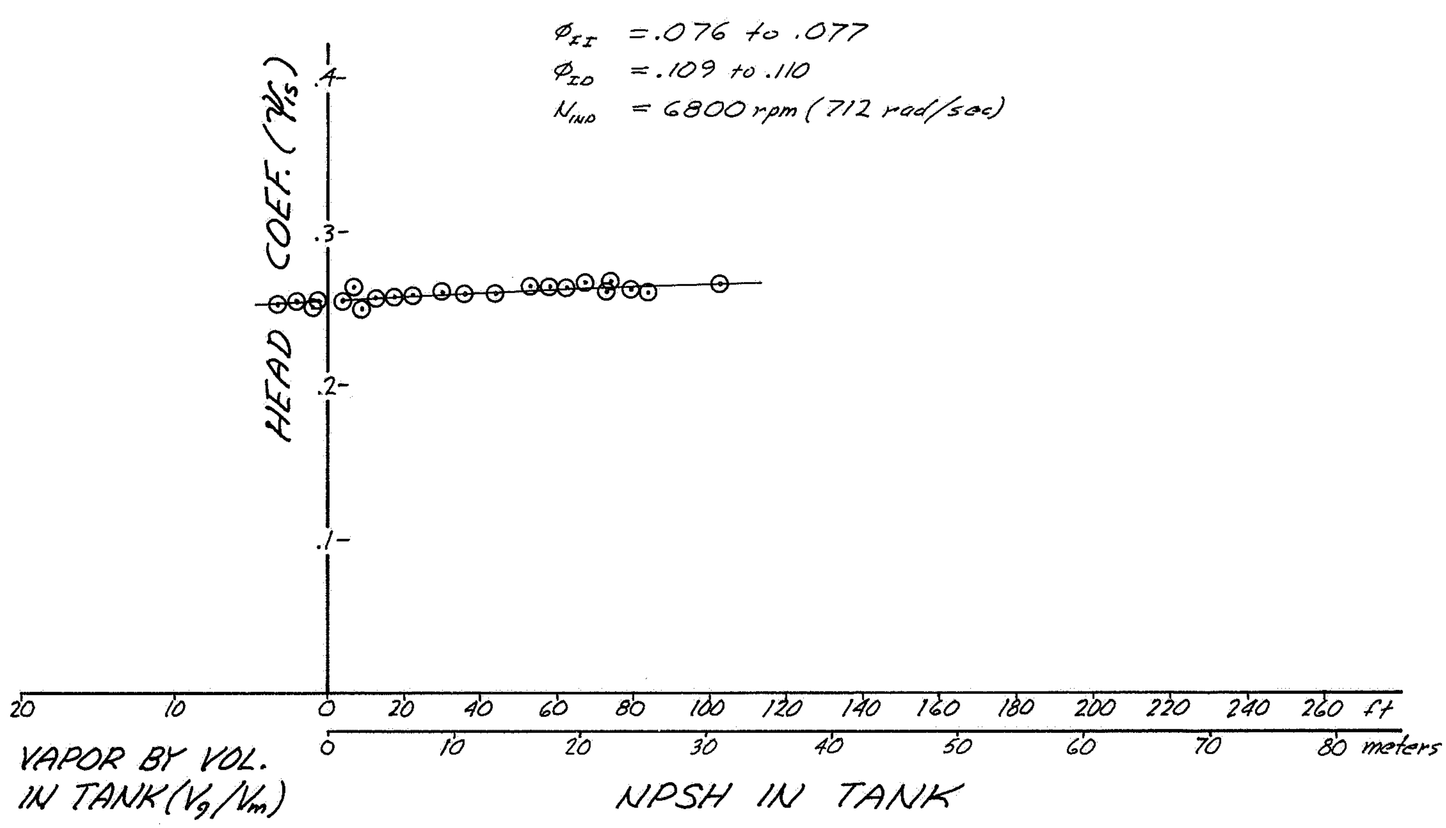


Figure 46. - Inducer Performance, Head Coefficient vs Vapor by Volume and NPSH in Tank, Test -005 (6800 rpm).

Figures No. 47 and No. 48 show head loss as a function of suction specific speed as well as a function of cavitation parameter, τ, from positive to saturation suction condition at the inlet of the low-speed stage. The relative trend for the losses are shown, but there are discrepancies within the trend because of the accuracy of the measurements and the interstage conditions. For example, if the worst conditions for error occur at a pressure rise of 30 psi (20.68 newton/cm^2), the error in the pressure rise would be 0.75/30 or 2.5%.

In general, the head rise-NPSH characteristics of the inducer exhibit the same gradual positive downslope observed in most previous tests of low NPSH hydrogen inducers and pumps. This would not appear to be a problem for rocket engine applications; therefore, relatively low or zero tank NPSH appears to be practical over a relatively wide flow coefficient for low-speed boost pumping type systems, even with relatively cold hydrogen.

3. Over-All Pumping Systems and Stage-Matching Characteristics

The flow rate/speed interrelationship between the low- and high-speed stages is shown on Figures No. 49 and No. 50. Using these curves and the suction characteristic curves (ψ vs NPSH), it is found that the main-stage suffered essentially no loss in head rise from $\phi_{ms} = 0.053$ to approximately $\phi_{ms} = 0.140$ for tank conditions from positive NPSH to saturation conditions. This also is reflected on Figure No. 51, which shows that at a $\phi_{ms} = 0.140$ and saturation condition at the inducer inlet, cavitating head loss conditions will occur in the main-stage. At a NPSP value of 14.5 psia (9.99 newton/cm^2) and main-stage shaft speed of 22,000 rpm (2303 rad/sec), cavitation does not occur within the main-stage until $\phi_{ms} = 0.168$. Figure No. 50 also depicts the influence of turbine back pressure upon the low-speed shaft speed. Generally, at the same main-stage speed and flow coefficient, the inducer (low-speed stage) shaft speed decreases as the back pressure is increased. It should be noted from Figure No. 49 that the useful range of flow coefficient for the main-stage was greater than the low-speed stage (viz., the main-stage operation ranged from $\phi_{ms} = 0.053$ to 0.172 while the low-speed stage operation ranged from $\phi_{ID} = 0.071$ to 0.151). This is desirable, because the low-speed stage ordinarily has less cavitating operating (flow coefficient) range than the main-stage.

The composite operating map, Figure No. 52, is based upon the data acquired and the inducer shaft speed is based upon no restriction in the turbine exhaust line. The map depicts two inlet conditions to the low-speed stage, NPSP = 15 psia (10.34 newton/cm^2) and saturation conditions. Figure No. 53 illustrates the amount of pressure rise contributed by the low-speed stage to the main-stage pressure rise at a main-stage shaft speed of 22,000 rpm (2303 rad/sec).

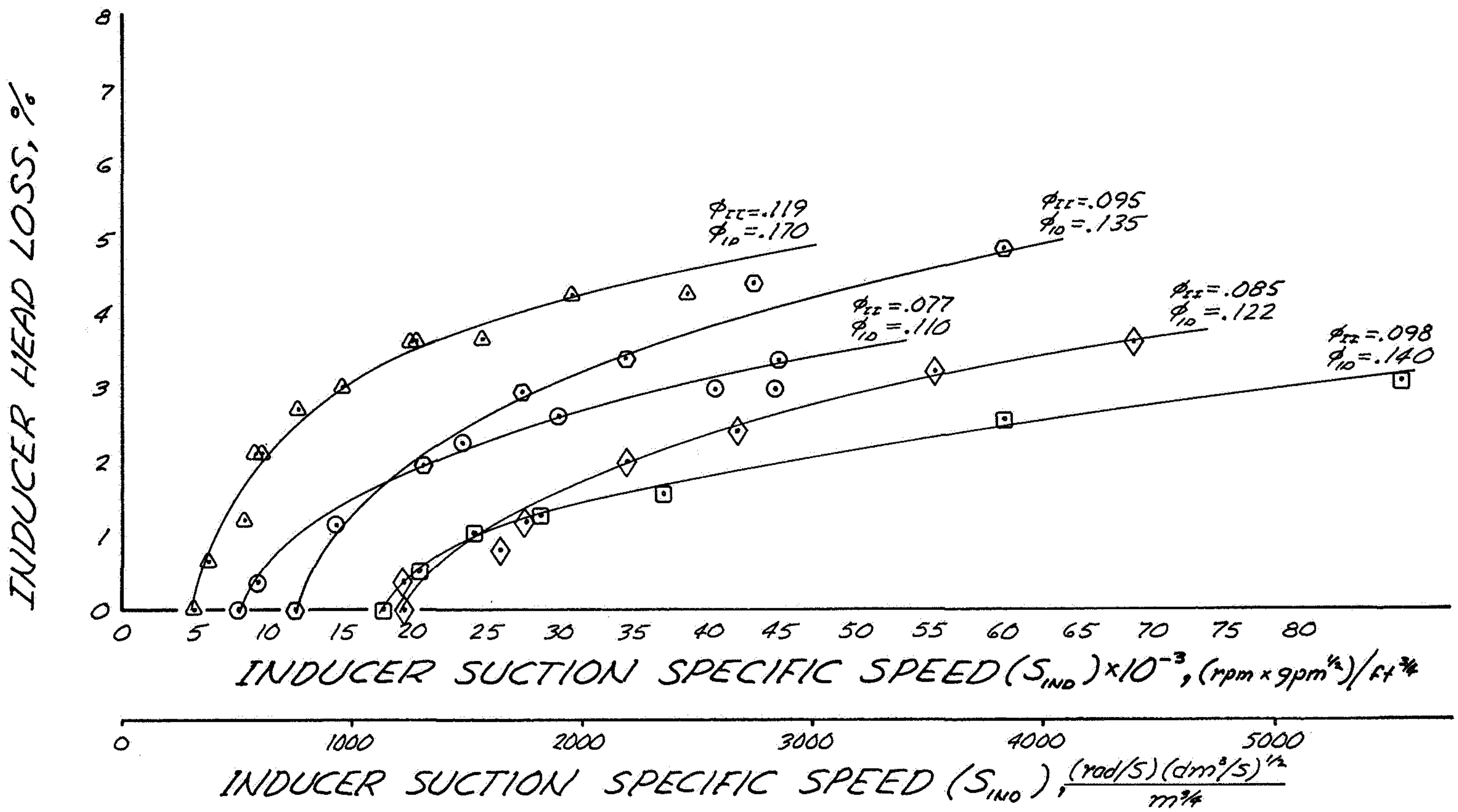


Figure 47. - Inducer Performance, Head Loss vs Suction Specific Speed.

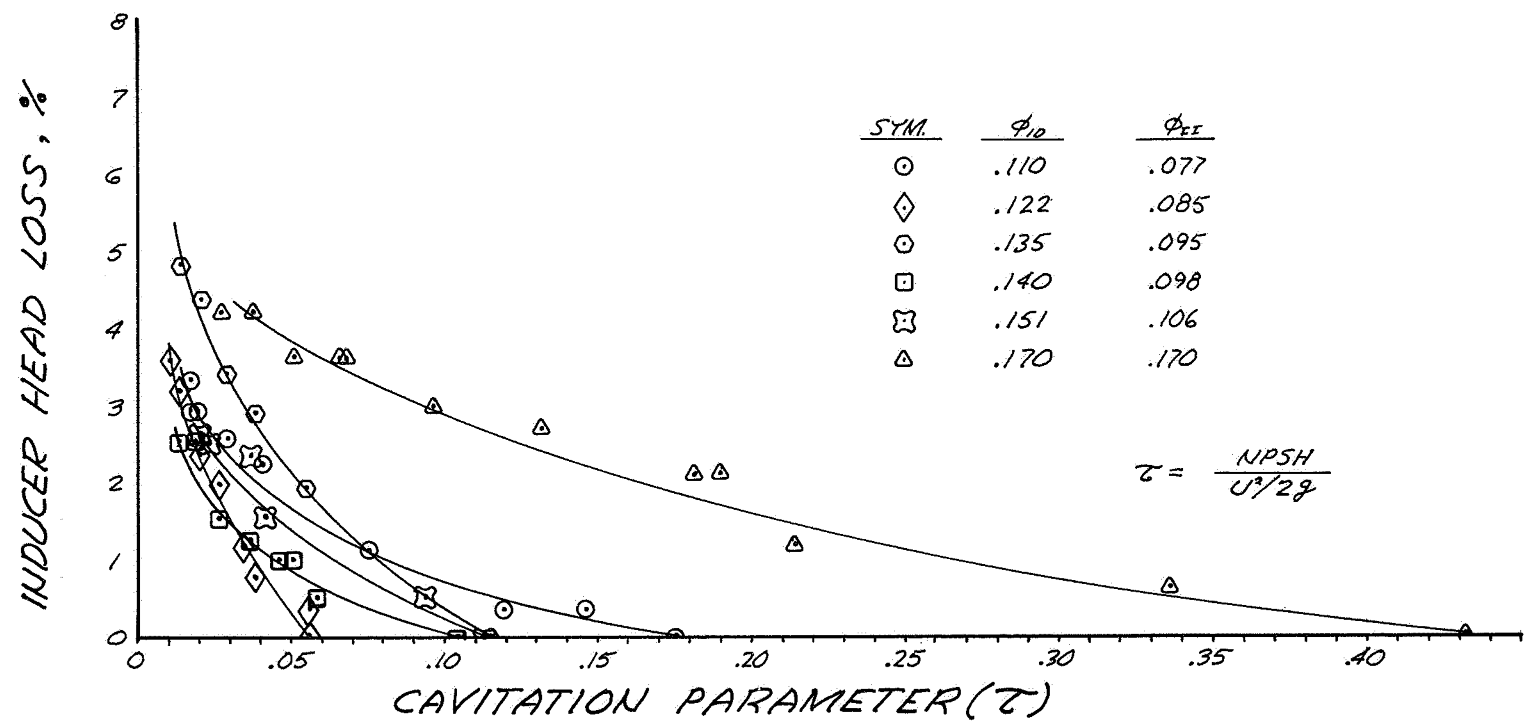


Figure 48. - Inducer Performance, Head Loss vs Cavitation Parameter.

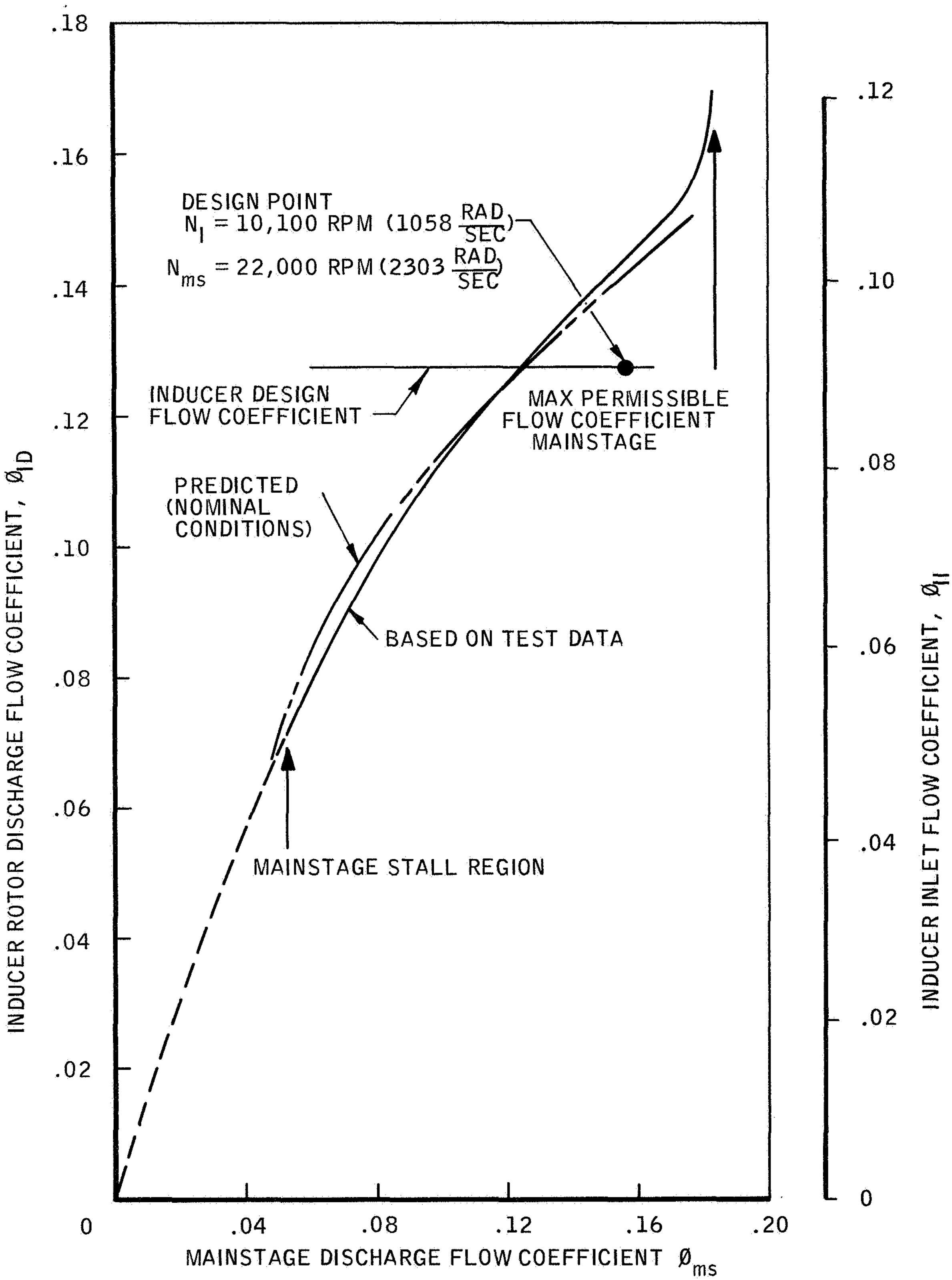


Figure 49. - Inducer Flow Coefficient vs Main-Stage Flow Coefficient.

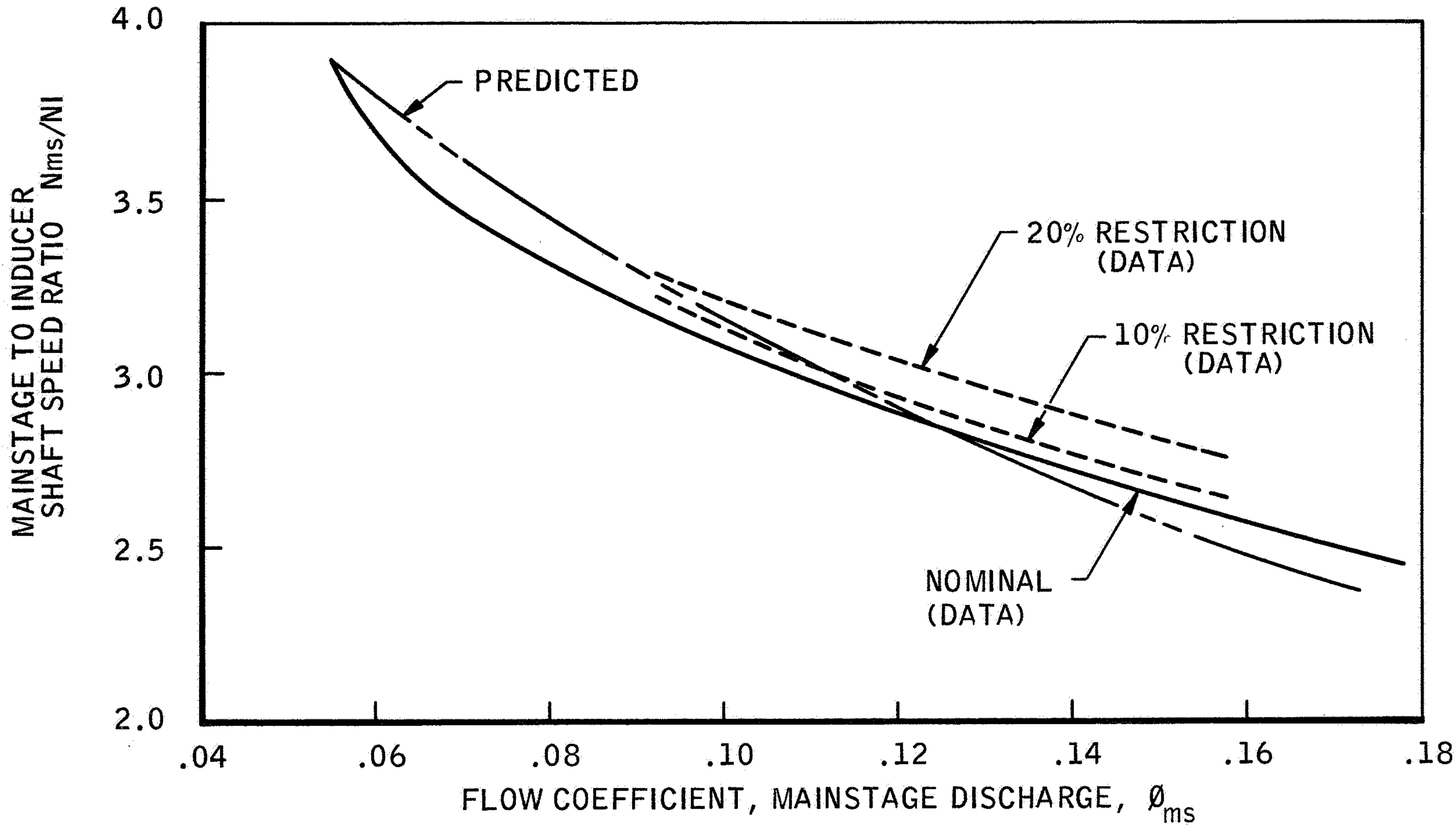


Figure 50. - Shaft Speed Ratio vs Flow Coefficient.

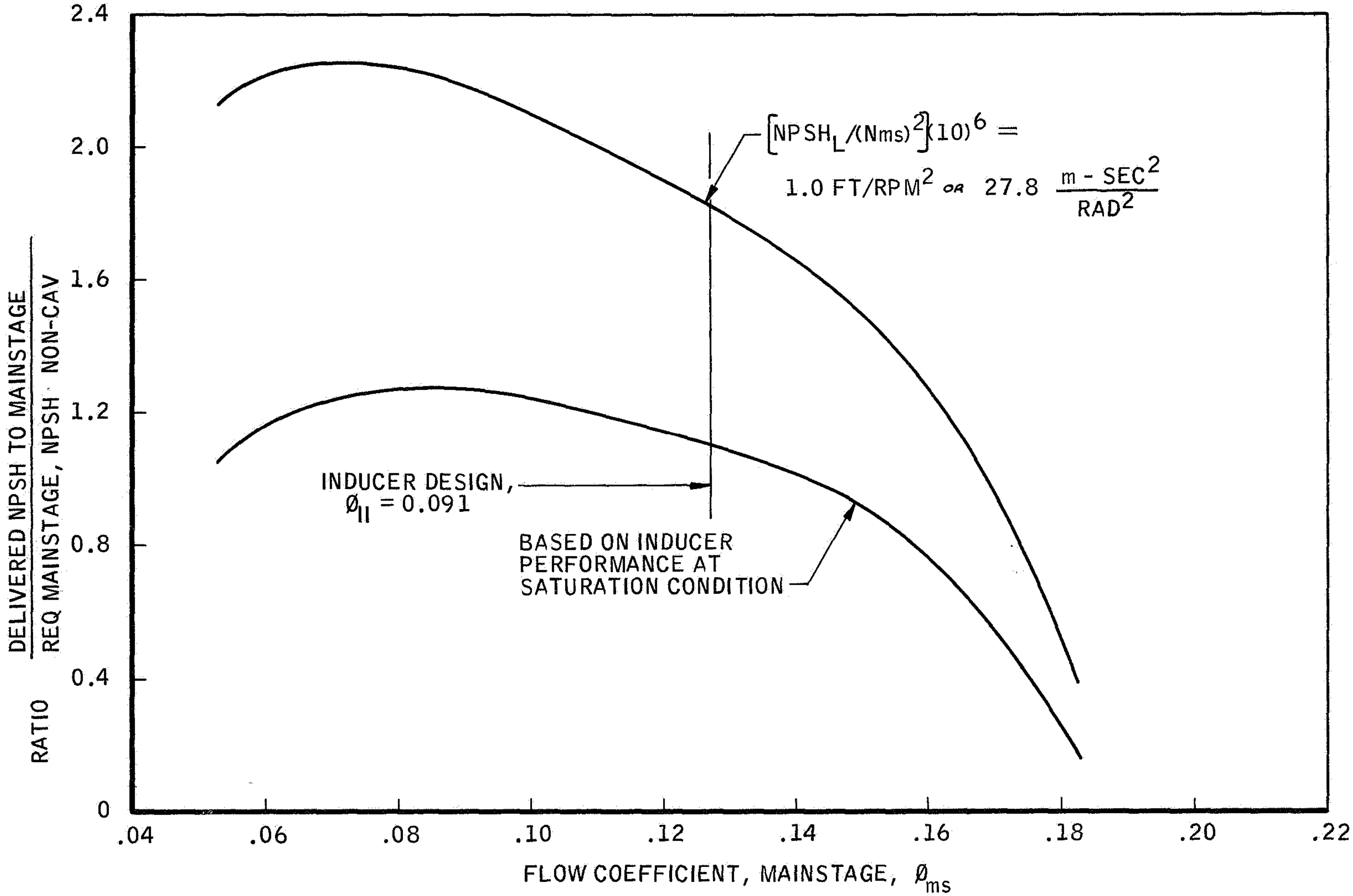


Figure 51. - Head Ratio vs Flow Coefficient.

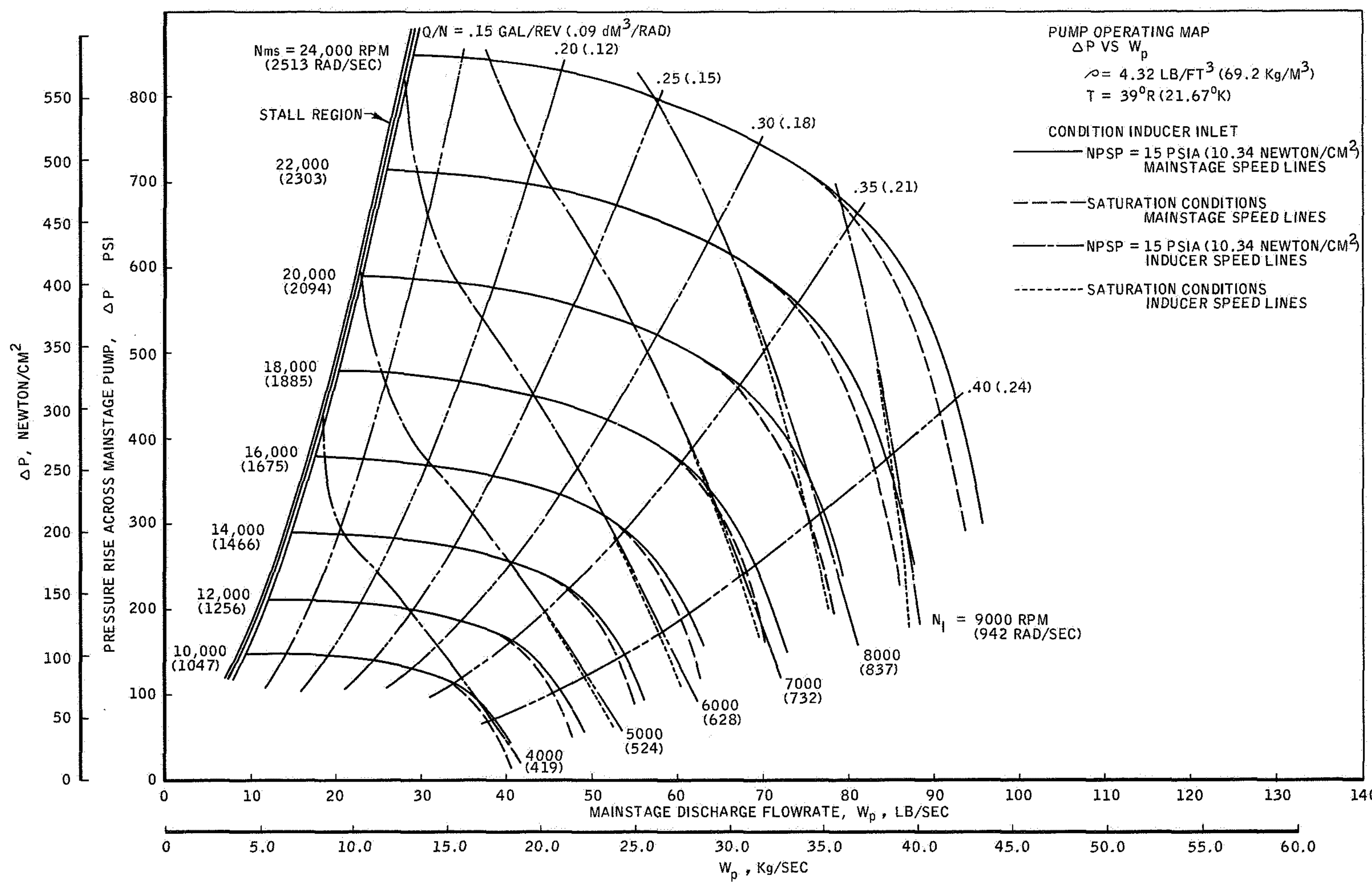


Figure 52. - Pump Operating Map.

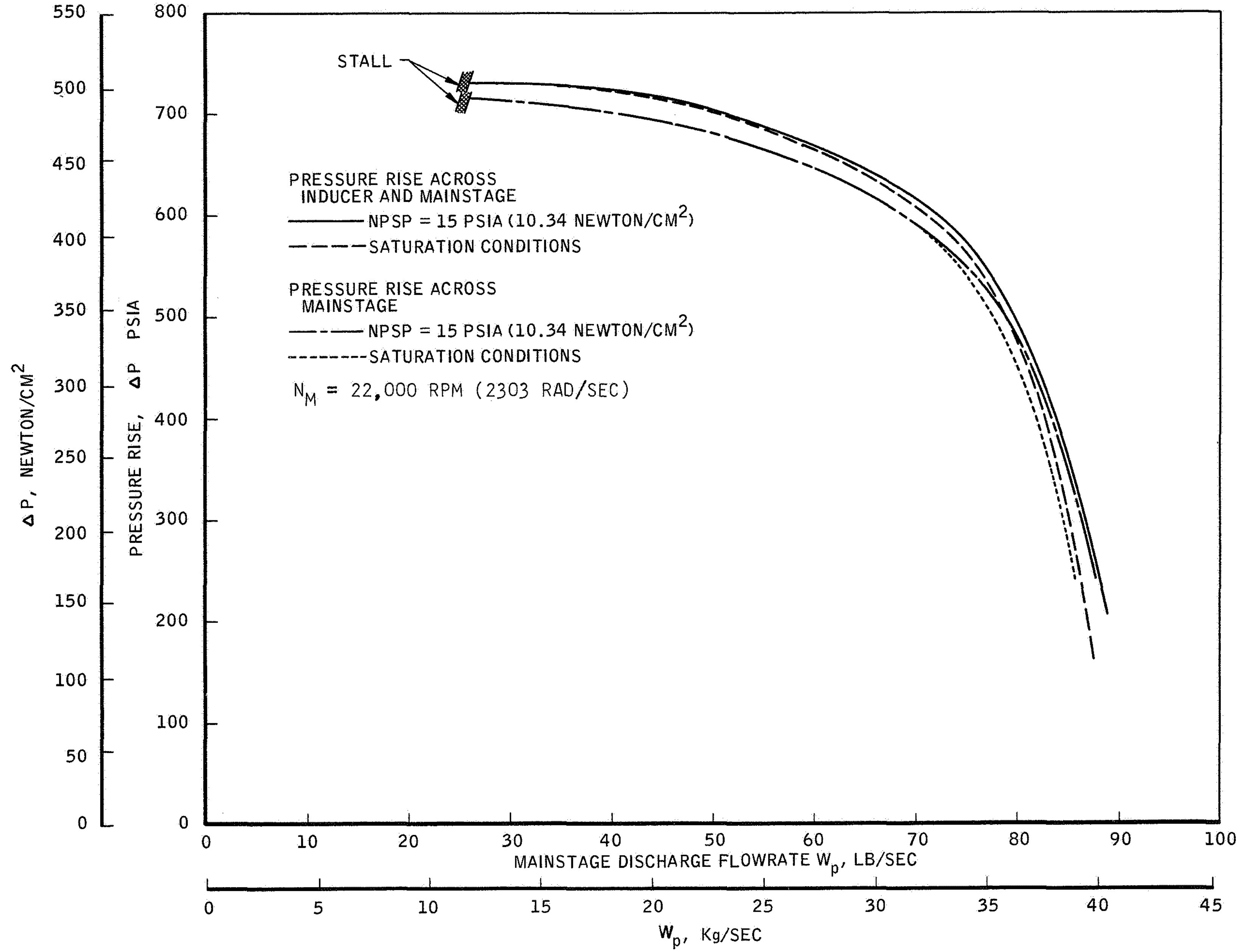


Figure 53. Pressure Rise vs Flow Rate

4. Transient Performance

The transient characteristics for the twin-spool pump are shown on Figures No. 54 through No. 60. The data from tests -003 and -004A are shown on Figures No. 54 and No. 55, respectively. During the pre-test transient prediction, it was found that the rotational acceleration of the inducer was such that there would be a period at which there will be a negative pressure rise across the low-speed stage. The data depict this condition starting at 73.9 sec in test -003 and 65.7 sec in test -004A. Figures No. 56 and 57 show transient start data. The transient speed ratio differs from the steady-state speed ratio by a factor 2 at the very beginning, but quickly return to the nominal ratio for steady-state operation. A satisfactory system bootstrap capability was demonstrated for the required transient durations and fluid suction conditions. The lag in inducer speed can be reduced if the mass of the rotor is reduced. Figures No. 58, No. 59, and No. 60 show rotational speed and pressure as a function of flow rate. A comparison of the three transient conditions shows that the relative slopes of the curves are almost identical with magnitude being the only difference. The magnitude primarily is a function of the tank pressure, P_{TK}.

5. Comparison with Other Boost Pump Types

The primary concern for rocket engine pumping application where the main-stage pump unit operates over a wide flow coefficient range is the corresponding flow coefficient range of the low-speed boost pump. The inducer tends to have a relatively narrow flow coefficient range of operation for low NPSH applications. Figure No. 61 presents a comparison of the various boost pump types investigated to date (Ref. 6, 10, and 11). As indicated, the twin-spool concept exhibits a desirably narrow inducer flow coefficient range. The narrower operating range allows the inducer to run closer at its best operating point, both for cavitation and efficiency, over the entire operating range of the unit. The partial flow hydraulic turbine drive types, both top turbine and hub turbine, tend to have less desirable characteristics, depending upon the head-flow slope of the main-stage pump, but characteristics similar to those of the twin-spool can be obtained if the turbine flow is throttled. The full-flow concept without stator vanes (Ref. 11) tends to have undesirable characteristics for wide flow coefficient range because of the hydraulic transmission requirements which are needed to ensure stable (hydraulically-locked) operation.

The twin-spool and partial-flow hydraulic turbine driven concepts are quite flexible with respect to capability for range of high-shaft/low-speed ratio as well as over-all boost pump head rise applicators. The full-flow concept is less flexible because hydraulic transmission design considerations place upper limits upon the permissible high-shaft/low-shaft speed ratio and system head rise.

All of the boost pump systems discussed above tend to have some speed build-up lag during engine thrust build-up transients. Only the partial-flow top-turbine-driven concept has been demonstrated (Ref. 12) to

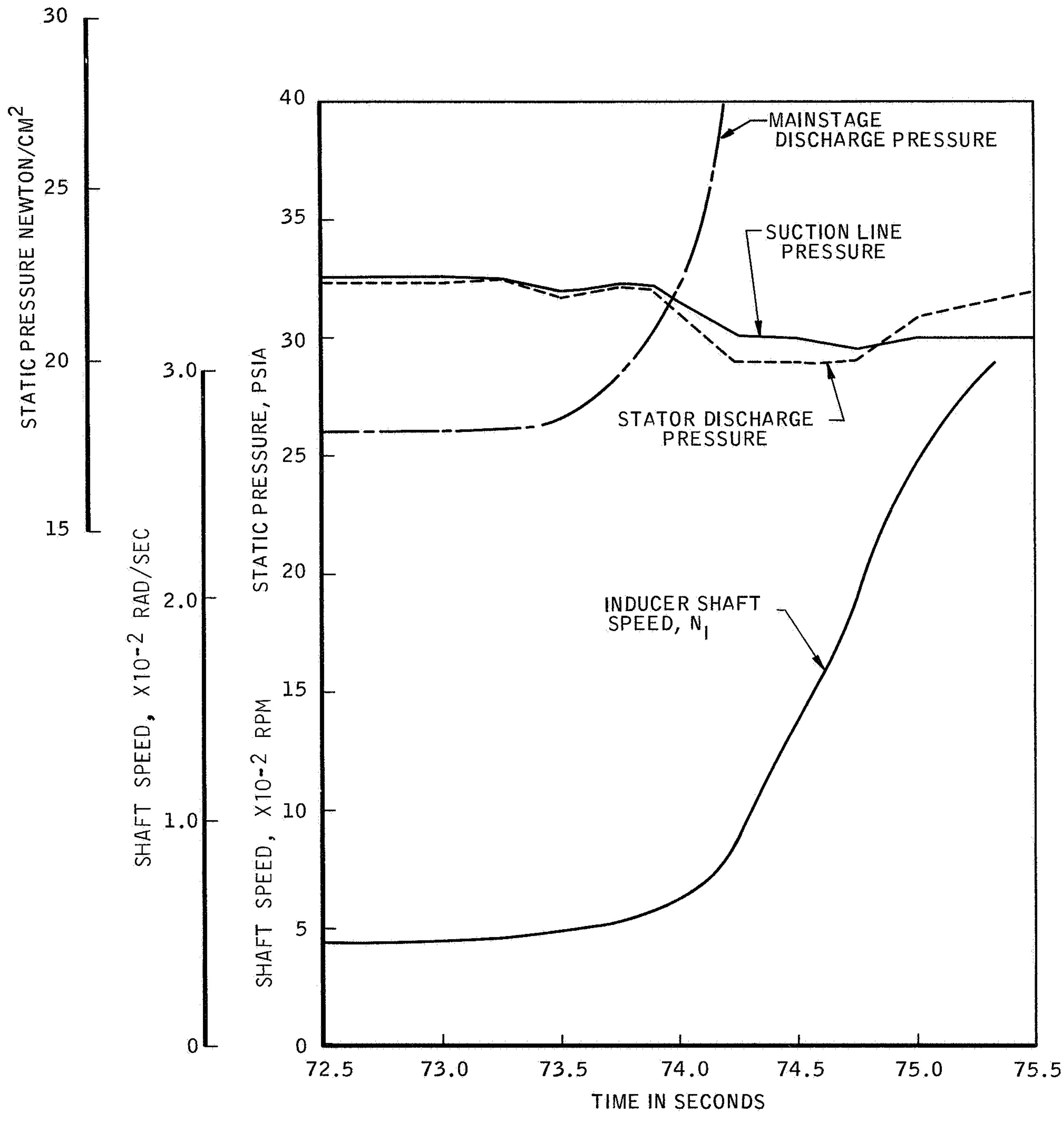


Figure 54. Transient Characteristics; Pressure, Speed vs Time, Test -003

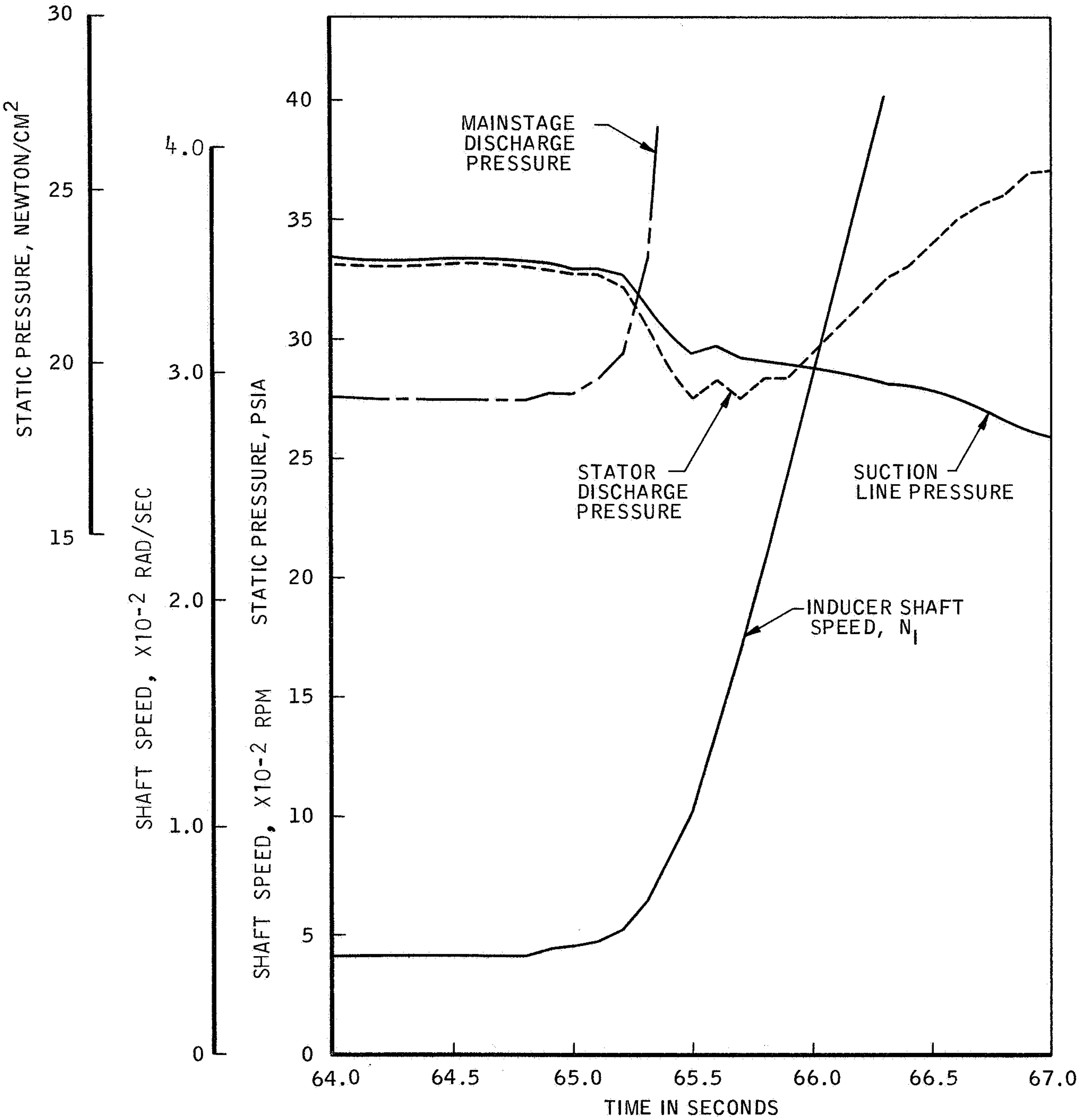


Figure 55. Transient Characteristics; Pressure, Speed vs Time, Test -004A

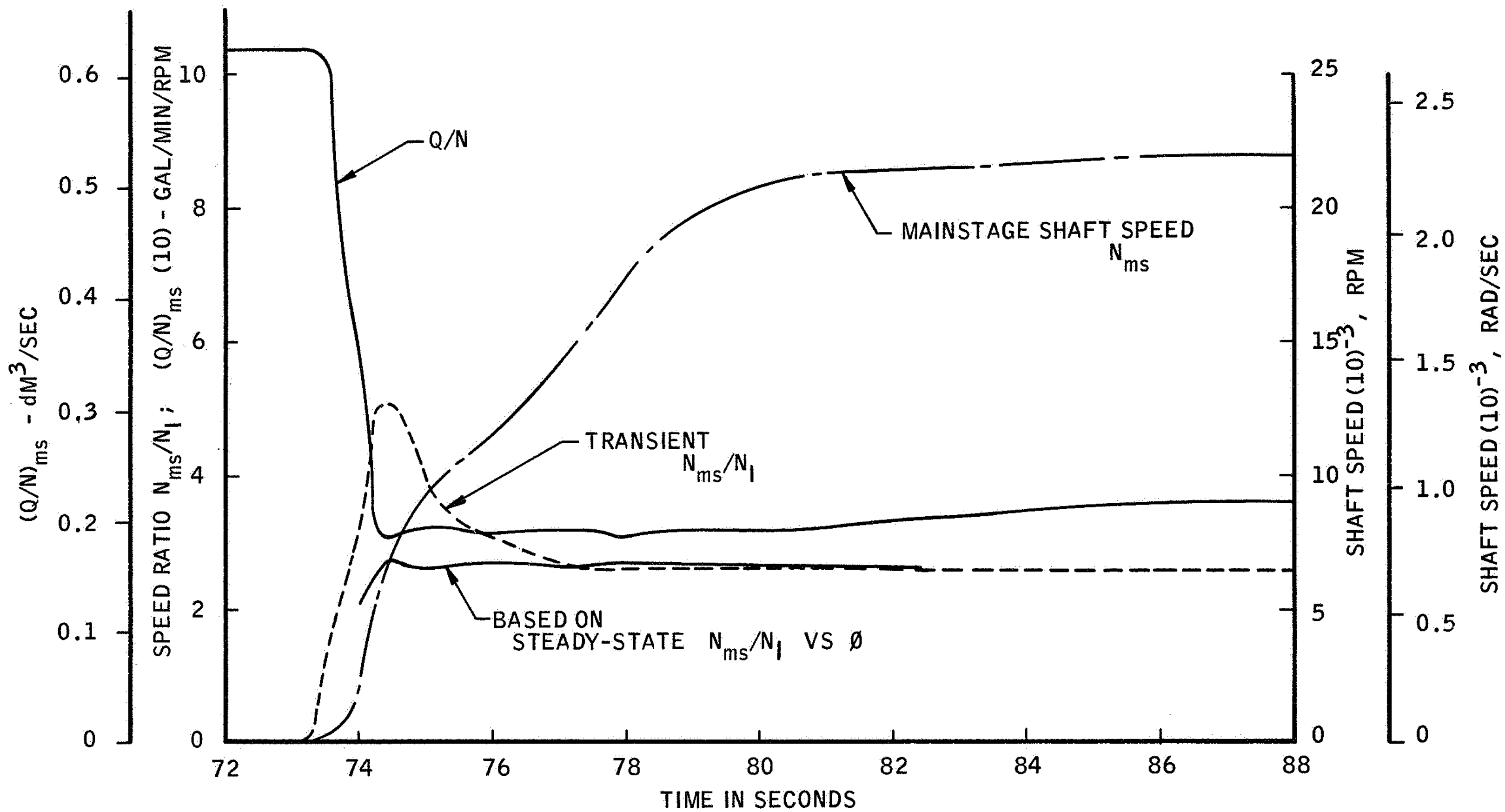


Figure 56. - Transient Characteristics: Q/N, N_{ms}/N_I vs Time, Test -003.

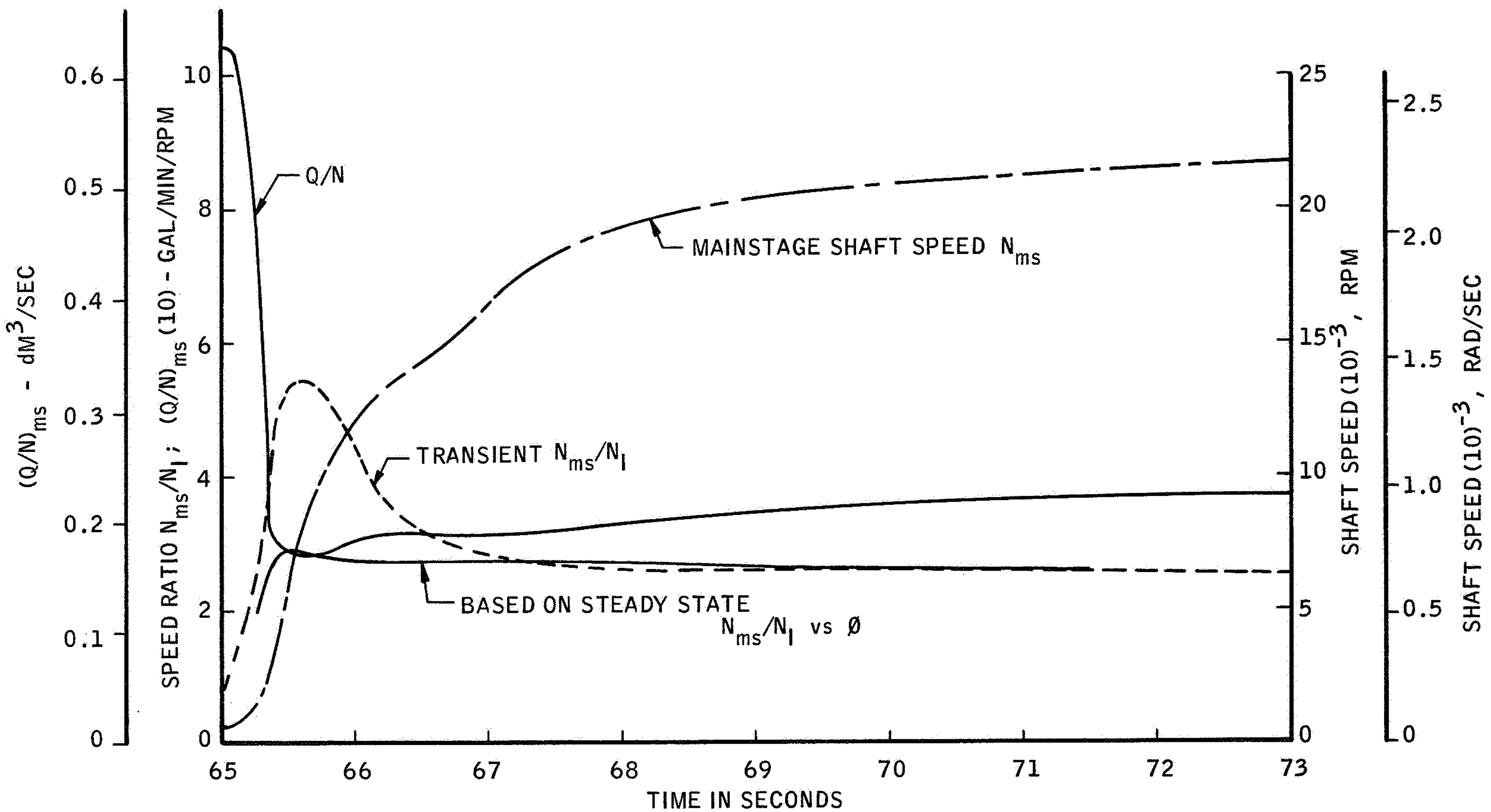


Figure 57. - Transient Characteristics: Q/N, N_{ms}/N_I vs Time, Test -004A.

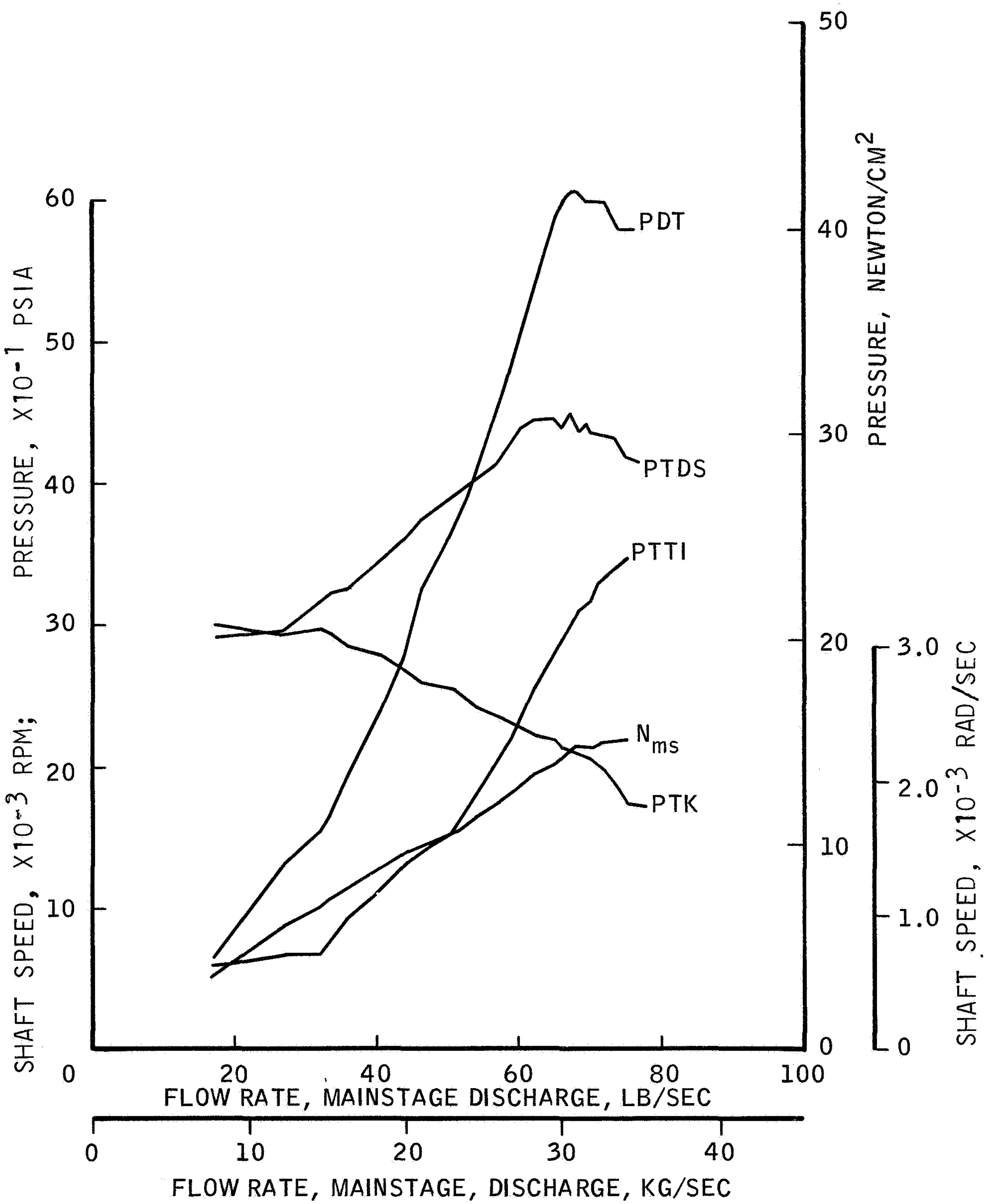


Figure 58. Transient Characteristics; N_{ms}, Pressure vs Flow Rate, Test -003

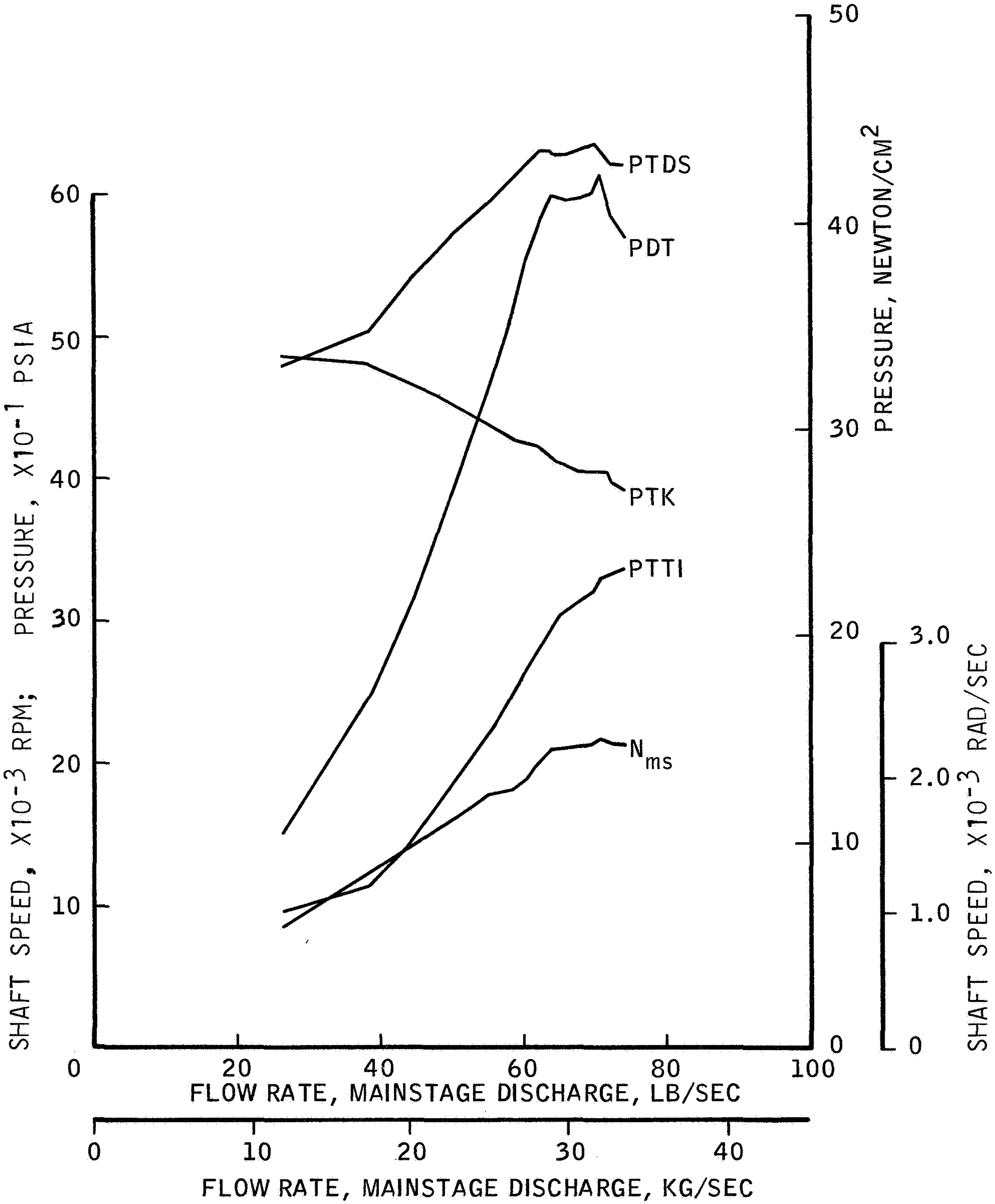


Figure 59. Transient Characteristics; N_{ms}, Pressures vs Flow Rate, Test -004

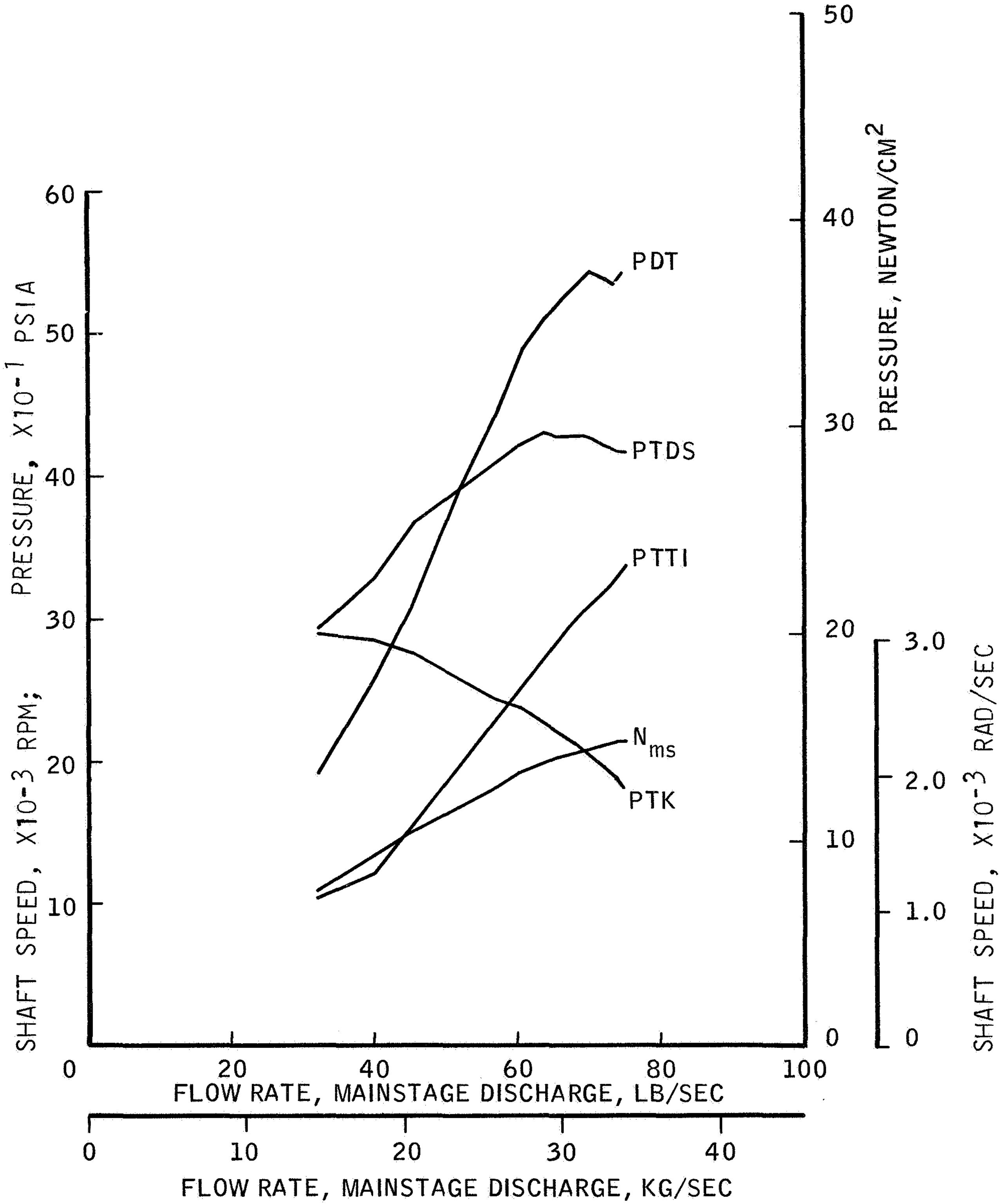


Figure 60. Transient Characteristics; N_{ms}, Pressures vs Flow Rate, Test -004A

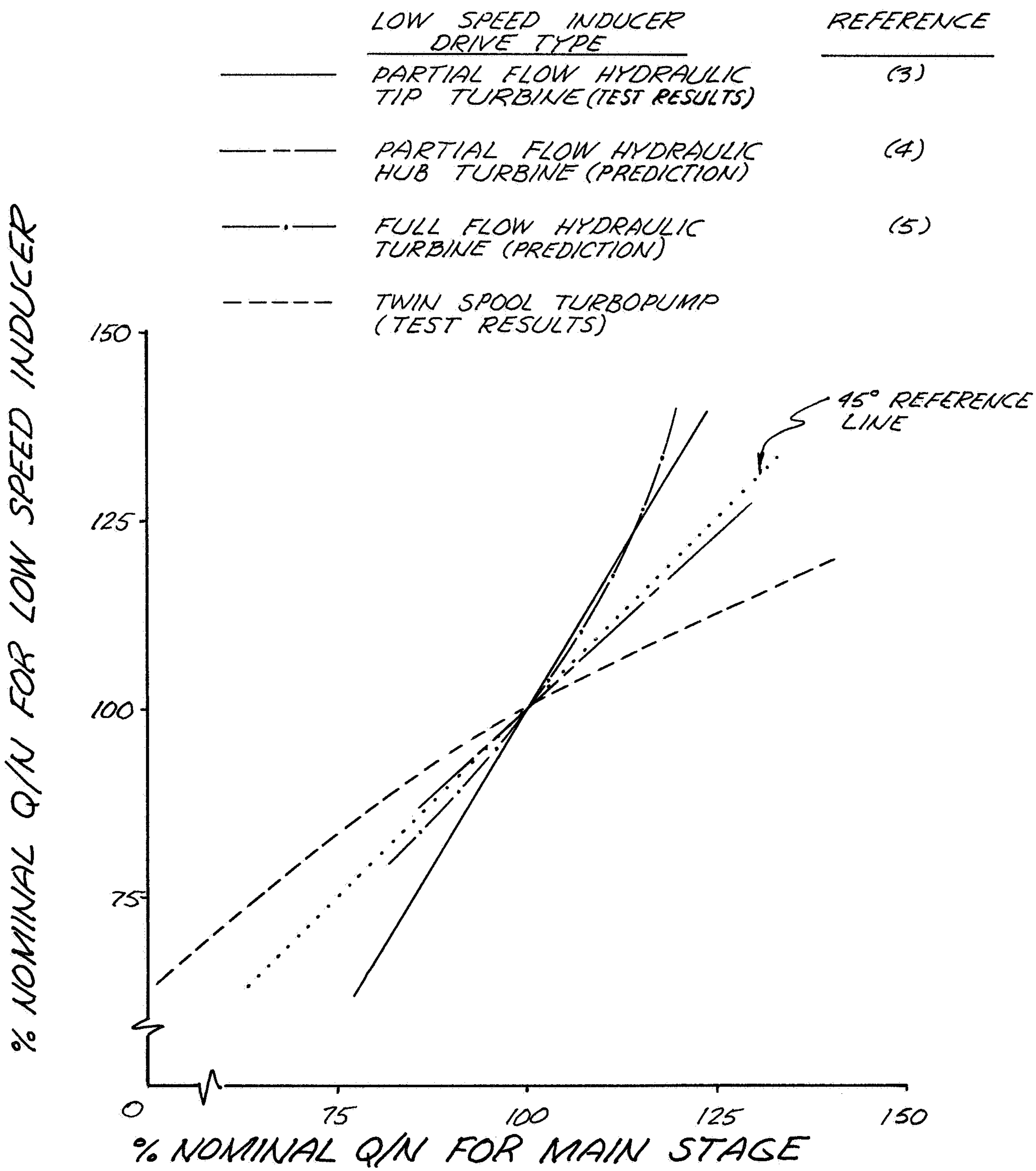


Figure 61. Comparison of Twin-Spool Turbopump Low-Speed Inducer and Main-Stage Pump Flow Coefficient Variation with Other Boost Pump Types

have a capability for start transients of less than one second, which are representative of some gas-generator (bleed-cycle) chemical engine starts. Work currently in progress or recently completed indicates that all the systems have adequate capability for transients of three seconds or more, which are typical of preburner and topping cycle chemical engines and all graphite core, nuclear rocket concepts.

The relative capability of the various systems for rapid chilldown and start with cryogenic propellants has not been investigated in any detail to date.

The use of liquid hydrogen presents no particular problem for the twin-spool and full-flow hydraulic turbine concepts. However, some potential problems with cavitation could be inherent in the partial-flow hydraulic turbine concepts because of the relatively high internal energy of the fluid leaving the hydraulic turbine and entering the main pump flow stream.

The partial-flow hydraulic turbine driven concepts permit operation of a boost pump remotely located from the main-stage pump while the full-flow, hydraulic-turbine-driven, and twin-spool concepts do not have this flexibility.

Gas-turbine-driven boost pumps (i.e., Centaur Vehicle pumps) having turbine pressurization which is independent of the engine tend to operate generally independent of the main engine pumps; therefore, this concept was not included in the above discussion.

6. High-Frequency Pressure Data

The oscillatory conditions of the pump suction and discharge pressure are depicted on Figures No. 62 through No. 67. Figure No. 62 shows plots of the maximum amplitude and the frequency at which the maximum amplitude occurred versus time for the start-up conditions of Test -004A (3 sec ramp). The values were taken from a spectrum analysis tabulation reduction program. Three predominant amplitudes are shown for the inducer inlet, at 0.35 sec, 2.75 sec, and 3.75 sec. The first major amplitude, at a time of 0.35 sec, is believed to have been caused by the opening of the turbine control valve. The third amplitude, at a time of 3.75 sec, occurred at a frequency of 980 hz and the inducer shaft speed of approximately 3000 rpm (314 rad/sec). The second major amplitude, at a time of 2.75 sec, occurred at a frequency of approximately 1180 hz. This is significant because it is the frequency at which the predominant amplitude for the main-stage discharge pressure oscillation occurred, at a time of 1.5 sec.

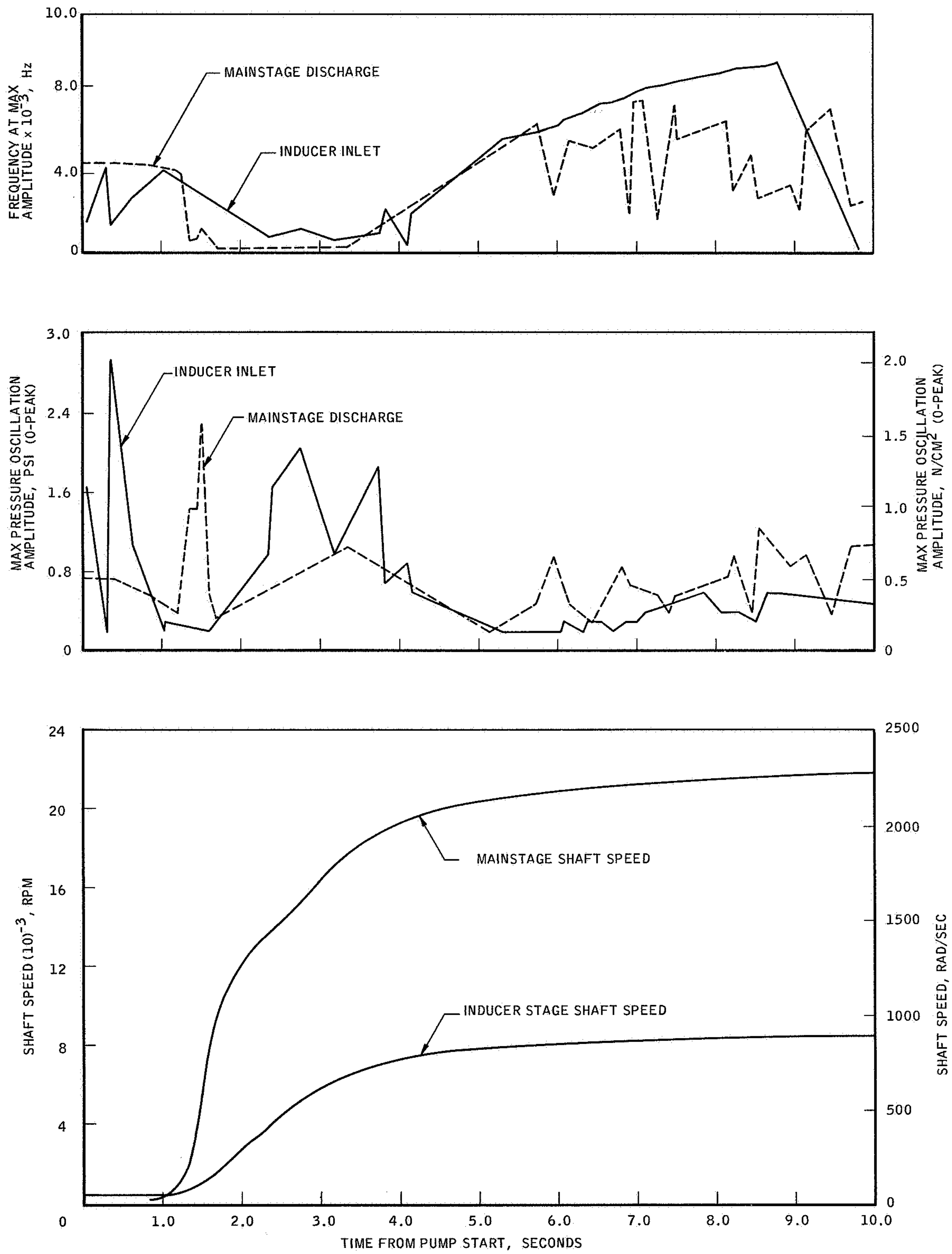


Figure 62. - Start Transient, Test -004A: Oscillation, Speed vs Time.

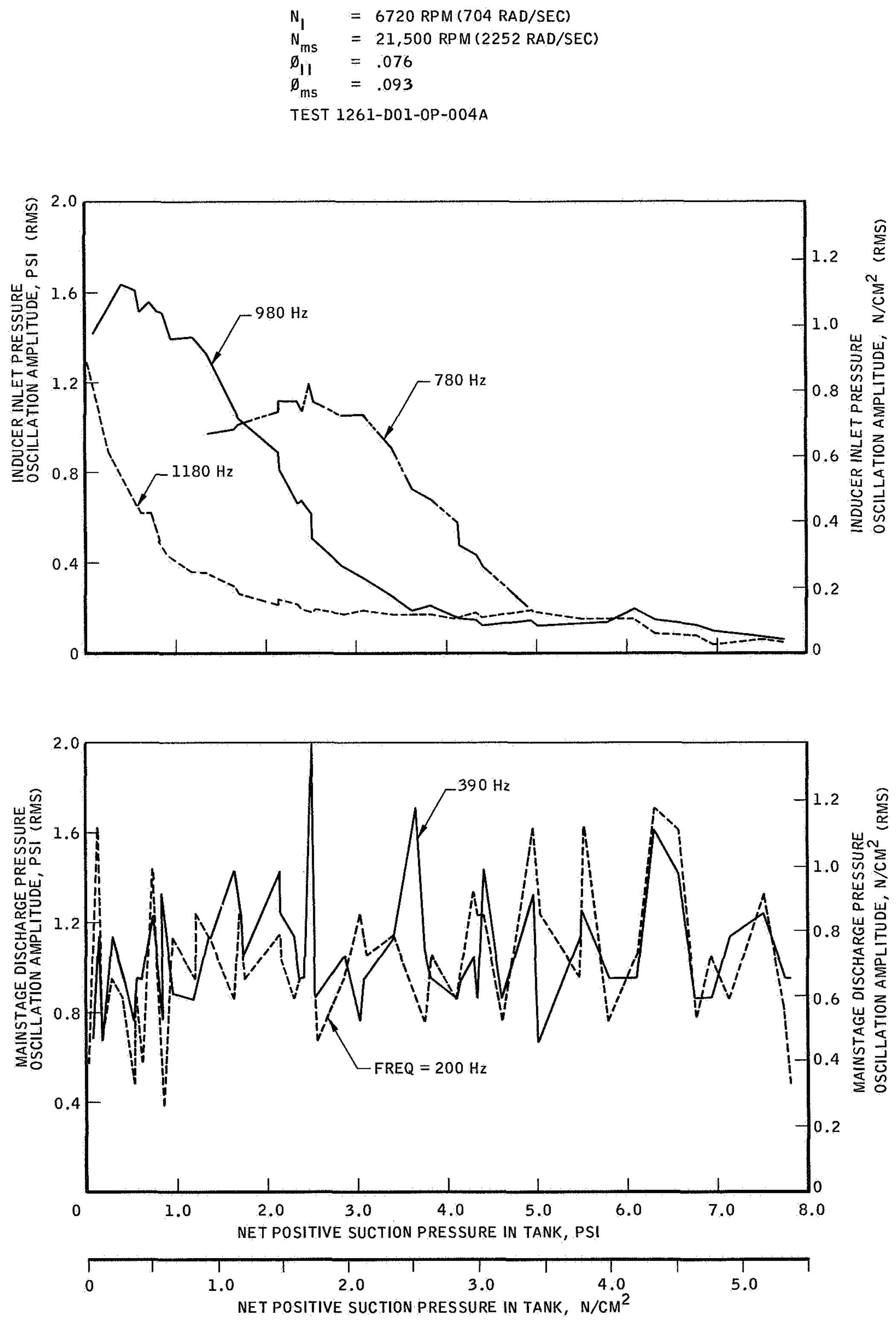


Figure 63. - Pressure Oscillation vs NPSP, Test -004A (N_I = 7460 rpm, N_{ms} = 21,500 rpm).

N_I = 7460 RPM (781 RAD/SEC)
N_{ms} = 22,000 RPM (2303 RAD/SEC)
ϕ_{I1} = .084
ϕ_{ms} = .110
TEST 1261-D01-OP-004A

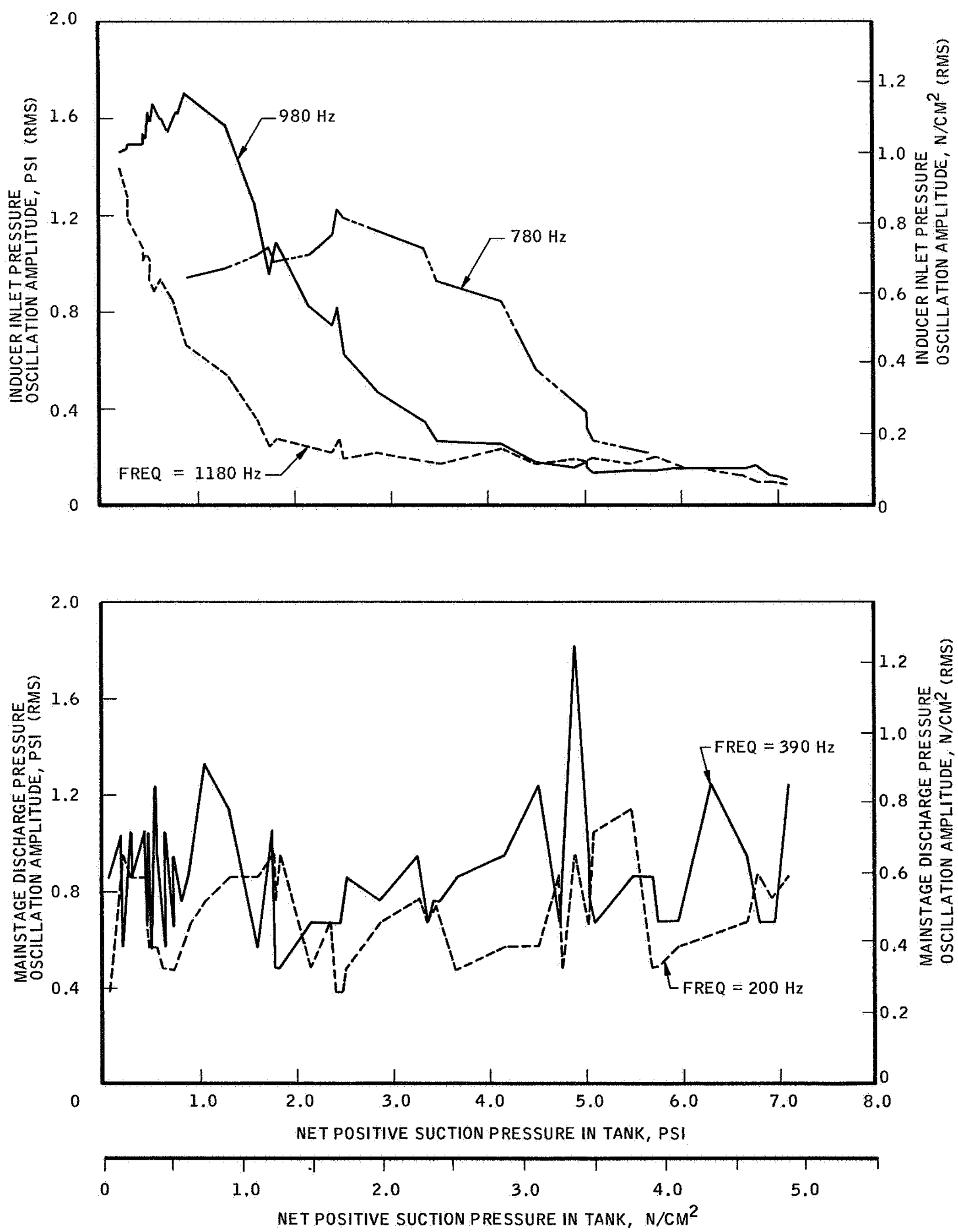


Figure 64. - Pressure Oscillation vs NPSP, Test -004A (N_I = 7460 rpm, N_{ms} = 22,000 rpm).

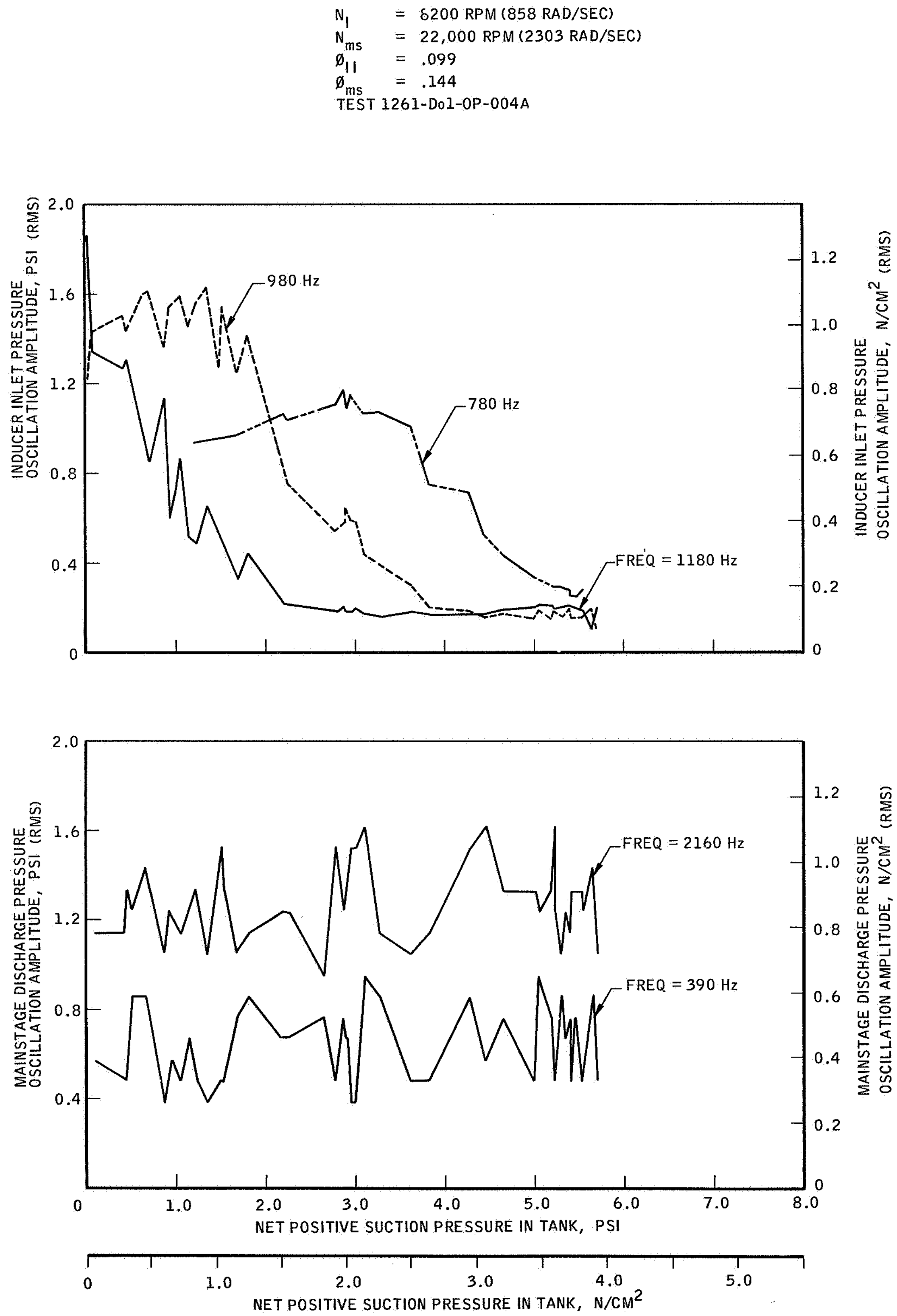


Figure 65. - Pressure Oscillation vs NPSP, Test -004A (N_I = 8200 rpm, N_{ms} = 22,000 rpm).

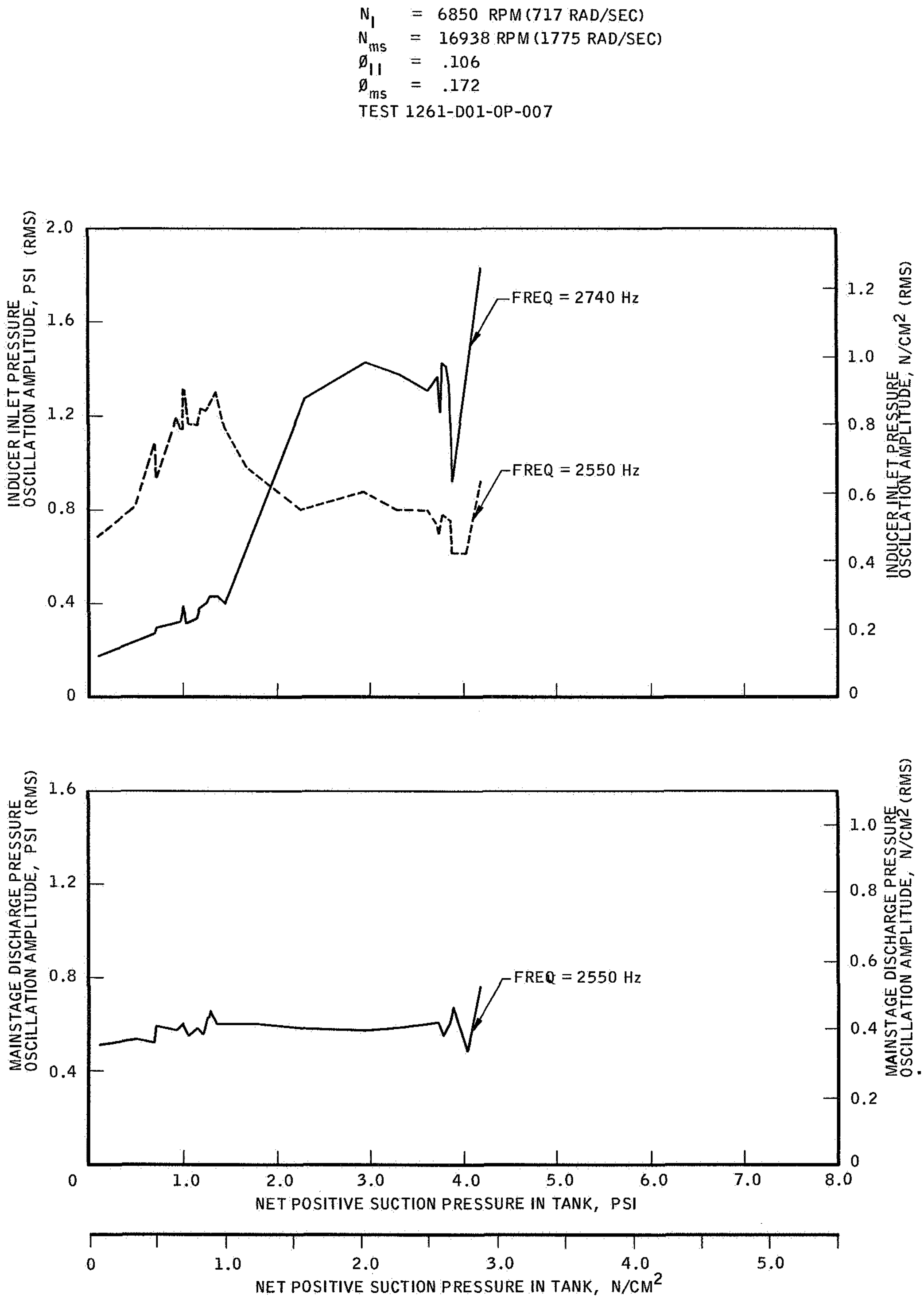


Figure 66. - Pressure Oscillation vs NPSP, Test -007 (N_I = 6850 rpm, N_{ms} = 16,938 rpm).

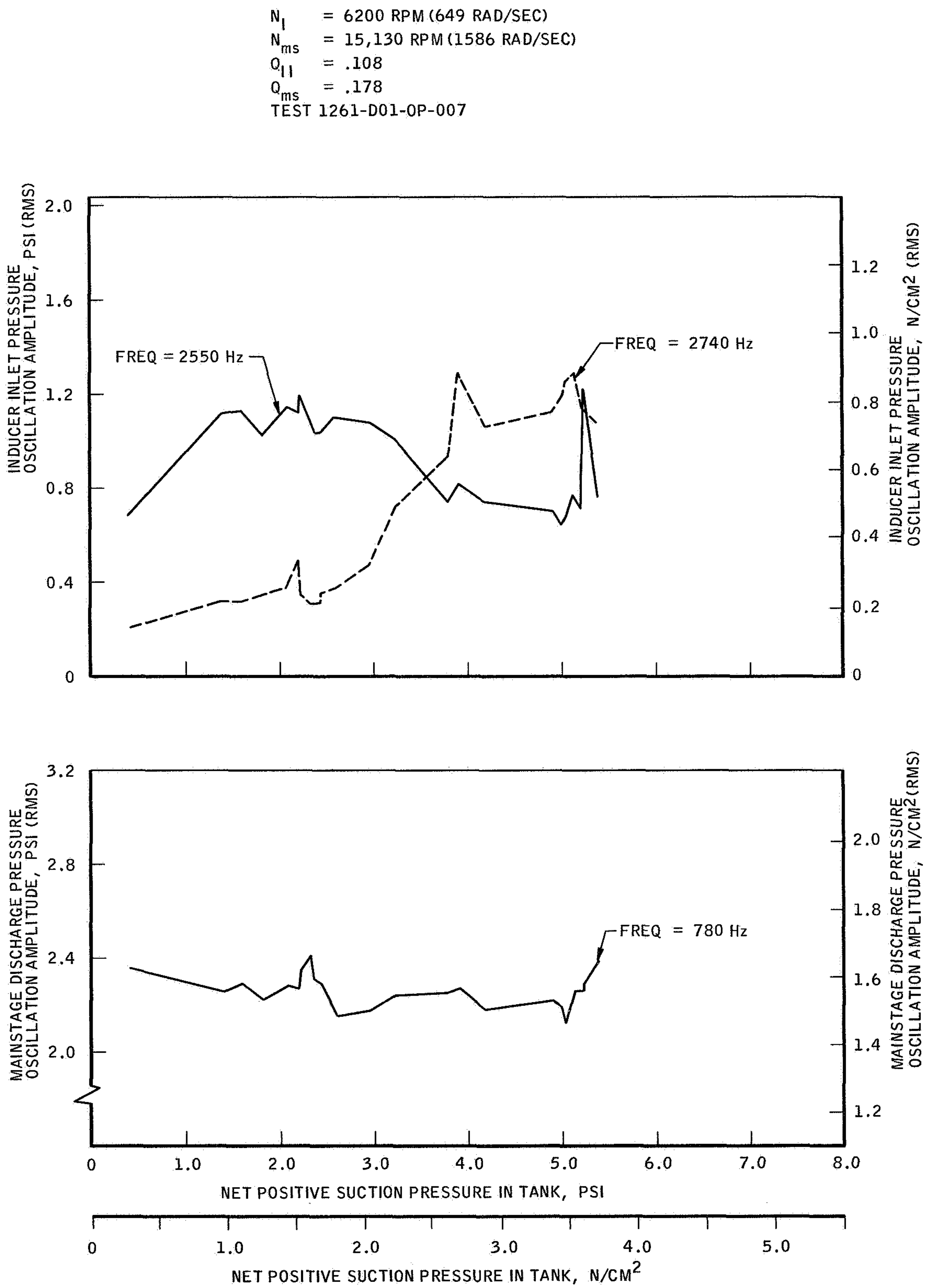


Figure 67. - Pressure Oscillation vs NPSP, Test -007 (N_I = 6200 rpm, N_{ms} = 15,130 rpm).

A comparison of these points reveals that both occur at approximately identical shaft speeds; with the earlier main stage, it was at 5500 rpm (575 rad/sec) and with the later inducer stage, it was at 5200 rpm (544 rad/sec). It is estimated that this range might be the fundamental bending critical frequency of the inducer shaft (low-speed shaft). Also, the fundamental frequency of the second-stage turbine rotor is in this range. The ratio of the measured frequency to rotational frequency is approximately 13.

The steady-state conditions where the suction pressure was varied are depicted for various flow coefficients on Figure No. 63 through Figure No. 67. The plots display data obtained from the spectrum analysis program of the major frequencies observed. As shown, for the suction conditions for main-stage flow coefficients from 0.093 to 0.144, three major frequencies were observed at 780 hz, 980 hz, and 1180 hz. The frequency of 780 hz is believed to be the natural frequency of the pressure perturbation while the 980 hz and 1180 hz frequency are probably related to the natural frequency of the low-speed shaft.

The main-stage pressure oscillation frequency for ϕ_{ms} = 0.093 to 0.144, seems to be 390 hz or approximately a multiple of 390 hz, which is approximately the rotational frequency (367 hz).

The predominant frequency for the high-flow, high NPSP portion of the tests at ϕ_{ms} = 0.172 and 0.178, was 2550 hz. The frequency of the pressure oscillation is approximately six times the rotational frequency; also, the expected fundamental frequency of the inducer blade was predicted to be between 2000 hz and 3000 hz. Additionally, the inducer inlet exhibited high amplitude 2740 hz oscillations at the ϕ_{ms} = 0.172 condition for NPSP values ranging from 2 to 5.

The predominant frequency range notices during the stall conditions of the main-stage at 22,000 rpm (2303 rad/sec), for both the section and discharge pressures, was 4900 hz to 5680 hz. The maximum amplitude for the discharge oscillation was approximately 13 psi (9.0 N/cm^2); for the suction was 9.2 psi (6.3 N/cm^2). The data indicate that the pressure wave created within the main-stage is propagated upstream into the run tank during the main-stage stall.

F. CONCLUSIONS

1. The non-cavitating performance of both the low-speed and main stages was as expected considering the limitations imposed by the accuracy of interstage pressure and temperature measurements.

2. The flow coefficient range at zero tank NPSP exceeded design requirements.

3. The system demonstrated a satisfactory pumping capability over the design flow range while ingesting 30% vapor by volume in the low-speed inducer suction annulus.

4. The system demonstrated a capability for flow rate-pressure-speed build-ups to nominal steady-state values in approximately 3 sec. A low pre-start NPSP value could not be used because of test facility limitations; however, bootstrapping to steady-state NPSP values of approximately 1 psi and 0 psi were demonstrated for the nominal 3 sec and 6 sec start transients, respectively.

5. The twin-spool concept exhibited generally good hydraulic characteristics during steady-state and transient applications. Based upon the testing results obtained to date, it appears that this system is one of the more promising alternatives to two-phase/hydrogen pumping.

IV. INDUCER TURBINE FLUID DYNAMIC DESIGN AND PERFORMANCE EVALUATION

A single-stage, axial-flow turbine was designed for the Twin-Spool Turbopump feasibility demonstration. A NERVA technology turbopump provided the main stage while a new turbine-driven inducer constituted the inducer stage. Ambient temperature gaseous hydrogen was used as the turbine drive gas throughout the testing.

The primary purpose of the program was to demonstrate the feasibility of the twin-spool concept; therefore, no optimization of the turbine configuration was considered justified.

The low power and speed dictated by the inducer requirements and a high exit flow Mach number at the main turbine exit led to very unconventional turbine blading and low design point efficiency. This efficiency was correlated by a simplified blade loss analysis, using the Soderberg approach.

In addition to the design-point efficiency prediction, off-design performance curves were estimated and used to calculate the equilibrium conditions for the main turbine and the inducer turbine running in series over a wide operating range.

Finally, turbine test data from five turbopump tests, using room temperature hydrogen for the turbine drive, were evaluated and compared with predicted performance.

A. DESIGN ANALYSIS

1. Main Turbine Operating Point

The main turbine power required to drive the (main-stage) impeller at design Q/N and a speed of 22,000 rpm (2310 rad/s) was calculated to be 4610 shp (3438 kw). The hydrogen gas temperature was assumed to be 1200°R (667°K) for the design calculations.

Test stand exhaust line impedance and the anticipated pressure drop across the inducer turbine established the main-stage exit static pressure of 45 psia (31 n/cm^2).

The plots of the main-stage flow-parameter and static-efficiency characteristics are shown on Figures No. 68 and No. 69, respectively. These plots are based upon previously obtained experimental data.

The total-to-static pressure ratio across the main turbine was determined by iteration to be 7.31. Inlet total pressure is:

$$\begin{aligned} P_{t0'} &= (PR)(P_{2'}) \\ &= (7.31)(45) = 329 \text{ psia } (227 \text{ N/cm}^2) \end{aligned}$$

For a pressure ratio of 7.31, the value for the flow parameter from Figure No. 68 is:

$$\frac{\dot{W}\,(T_{t0'})^{1/2}}{P_{t0'}} = 0.584 \text{ (0.286 SI units)}$$

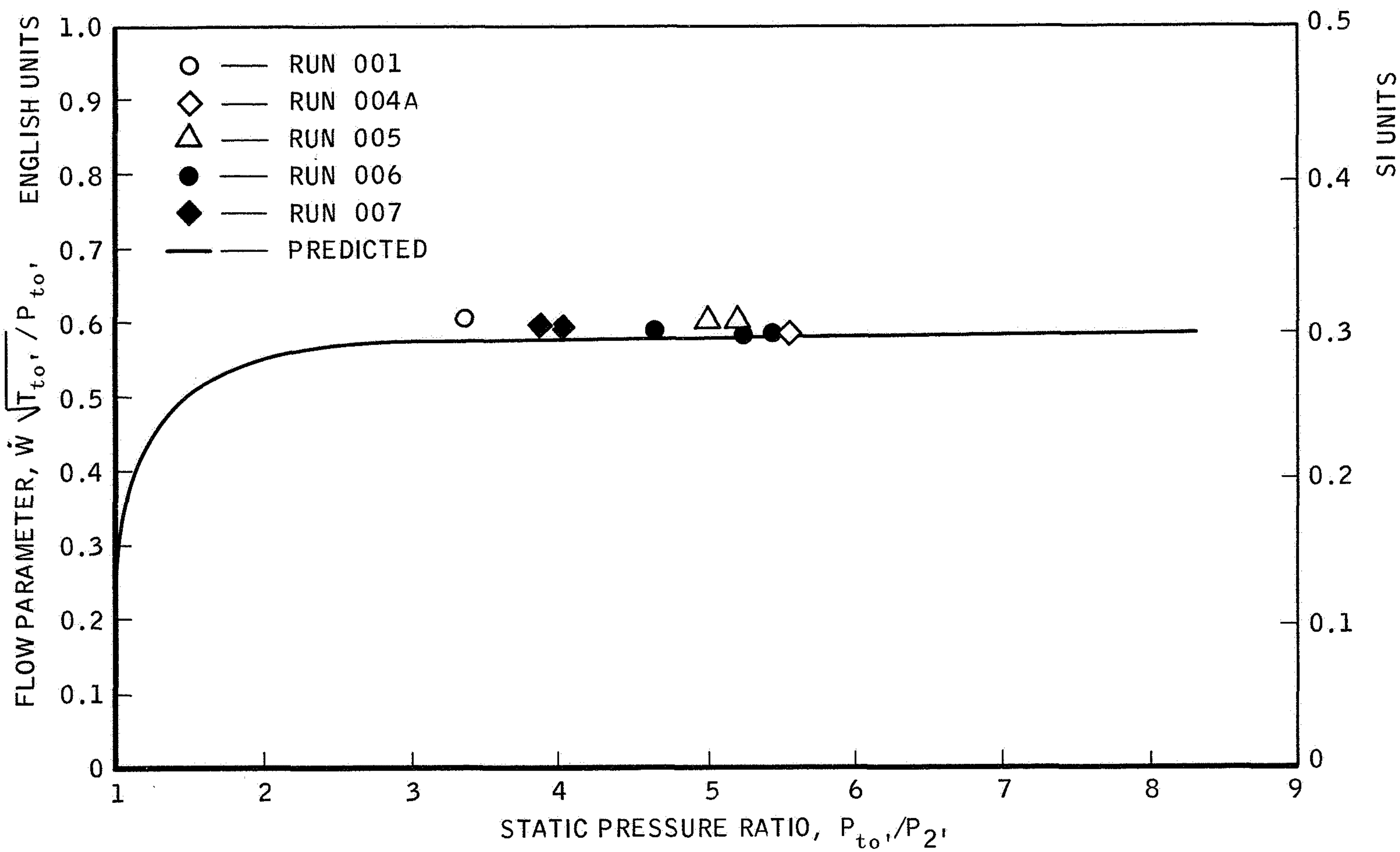


Figure 68. Flow Parameter vs Pressure Ratio (Main Turbine)

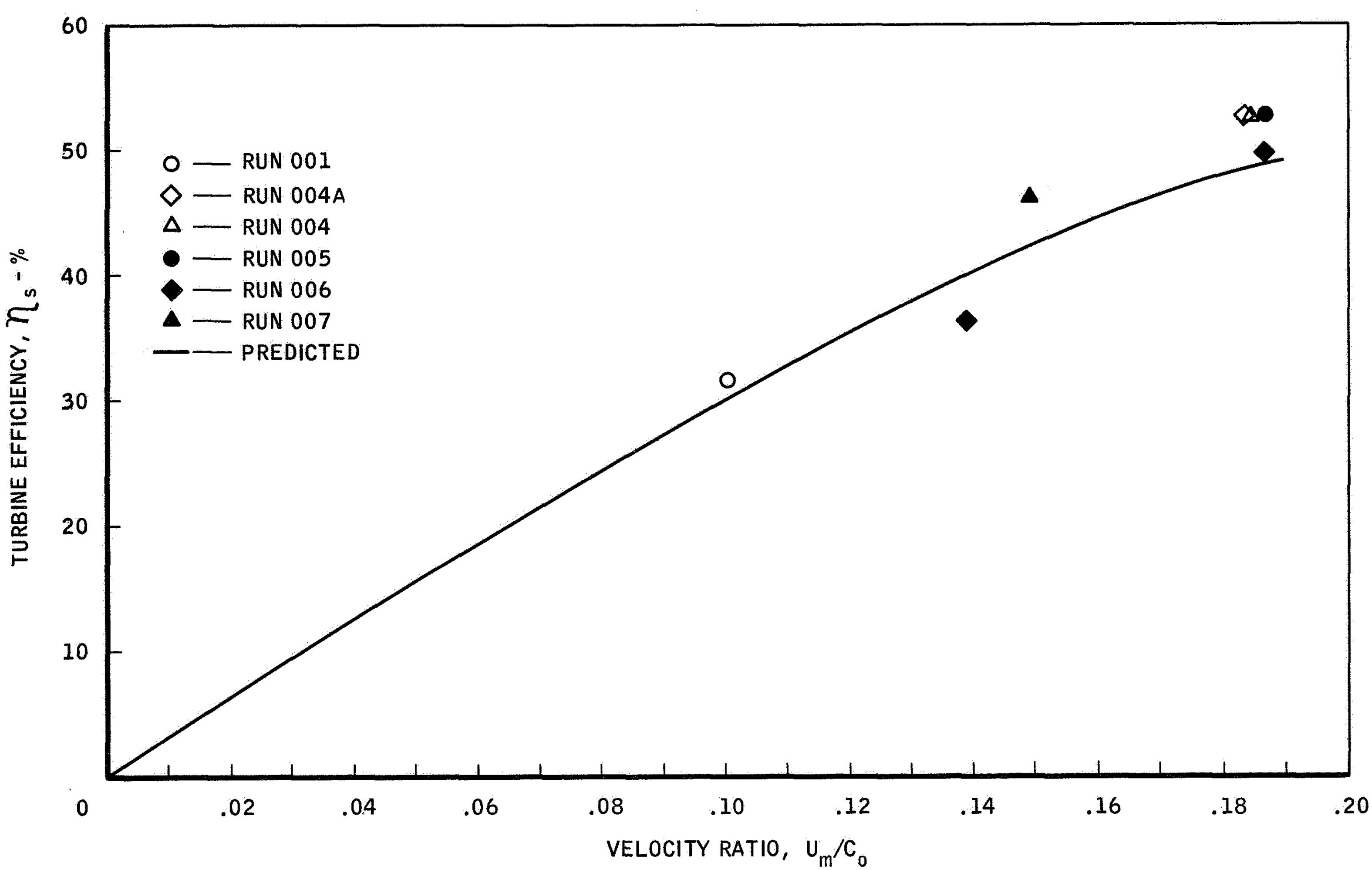


Figure 69. - Static Efficiency vs Velocity Ratio (Main Turbine).

and the flow rate is:

$$\dot{W} = \frac{0.584\ P_{t0'}}{(T_{t0'})^{1/2}} = \frac{(0.584)(329)}{(1200)^{1/2}} = 5.54\ \text{lb/sec}\ (2.51\ \text{kg/s})$$

The isentropic enthalpy change is:

$$\Delta H_i = C_p\ T_{t0'}\ [1 - (1/PR)^{\gamma-1/\gamma}]$$

where:

$$\gamma = 1.395$$

$$C_p = 3.482\ \text{Btu/lb-°R}\ (14{,}569\ \text{J/kg-°K})$$

$$\Delta H_i = (3.482)(1200)\ [1 - (1/7.31)^{0.395/1.395}]$$

$$\Delta H_i = 1799.7\ \text{Btu/lb}\ (861{,}603\ \text{J/kg})$$

The spouting velocity is:

$$C_o = (2\ g\ J\ \Delta H_i)^{1/2}$$

$$C_o = [(2)(32.174)(778.2)(1799.7)]^{1/2}$$

$$C_o = 9493\ \text{ft/sec}\ (2892\ \text{m/s})$$

The mean blade speed is:

$$U_m = \frac{\pi\ D_m\ N}{60} = \frac{(\pi)(10.92)(22{,}000)}{(12)(60)}$$

$$U_m = 1048\ \text{ft/sec}\ (319.4\ \text{m/s})$$

and the velocity ratio is:

$$\frac{U_m}{C_o} = \frac{1048}{9493} = 0.110$$

From Figure No. 69, for $U_m/C_o = 0.11$, the main turbine static efficiency is:

$$\eta_s = 0.327$$

The actual total enthalpy drop is given by:

$$\Delta H = \frac{550 \text{ shp}}{\dot{W} J}$$

$$= \frac{(550)(4610)}{(5.54)(778.2)} = 588.1 \text{ Btu/lb } (1{,}367{,}006 \text{ J/kg})$$

and the total temperature at the main turbine exit is:

$$T_{t2'} = T_{to'} - \frac{\Delta H}{C_p}$$

$$T_{t2'} = 1200 - \frac{588.1}{3.482} = 1031°R \ (572.8°K)$$

The gas temperature at the main turbine exit actually is diluted by the bearing coolant flow. The properties of this flow are estimated to be as follows:

$$\dot{W}_c = 0.62 \text{ lb/sec } (0.28 \text{ kg/s})$$

$$T_{tc} = 76°R \ (42.2°K)$$

$$C_{pc} = 3.491 \text{ Btu/lb-°R } (14{,}606 \text{ J/kg-°K})$$

Assuming perfect mixing, the inducer inlet total temperature is:

$$T_{mix} = \frac{C_p \dot{W} T_{t2'} + C_{pc} \dot{W}_c T_{tc}}{\bar{C}_p (\dot{W} + \dot{W}_c)}$$

where,

$$C_p = 3.482 \text{ Btu/lb-°R } (14{,}569 \text{ J/kg-°K})$$

$$C_{pc} = 3.491 \text{ Btu/lb-°R } (14{,}605 \text{ J/kg-°K})$$

$$\bar{C}_p = 3.483 \text{ Btu/lb-°R } (14{,}573 \text{ J/kg-°K})$$

$$\dot{W} = 5.54 \text{ lb/sec } (2.513 \text{ kg/s})$$

then

$$T_{mix} = \frac{(3.482)(5.54)(1031) + (3.491)(0.62)(76)}{3.483(5.54 + 0.62)}$$

$$T_{mix} = 935°R \ (519.4°K)$$

Next, the velocity diagram at the turbine exit is constructed by interation to satisfy the continuity equation. The axial velocity component is found to be:

$$V_{x2'} = 2535 \text{ ft/sec } (772.7 \text{ m/s})$$

and the whirl component is:

$$V_{u2'} = \frac{V_{x2'}}{\text{Cot } \beta_{2'}} - U_m$$

where

$$\beta_{2'} = \text{rotor blade angle} = 64° \ (1.117 \text{ rad})$$

$$V_{u2'} = \frac{2535}{0.4877} - 1048 = 4149 \text{ ft/sec } (1264.6 \text{ m/s})$$

The absolute velocity is:

$$V_{2'} = [(V_{x2'})^2 + (V_{u2'})^2]^{1/2}$$

$$= [(2535)^2 + (4149)^2]^{1/2}$$

$$V_{2'} = 4862 \text{ ft/sec } (1482 \text{ m/s})$$

Using these velocity components, the complete velocity diagram is constructed as shown on Figure No. 70.

The static temperature at the main turbine exit is:

$$T_{2'} = T_{mix} - \frac{V_{2'}^2}{2 \ g \ J \ \bar{C}_p}$$

$$= 935 - \frac{(4862)^2}{2(32.174)(778.2)(3.483)} = 799.5°\text{R } (444.5°\text{K})$$

Now:

$$\frac{T_{2'}}{T_{mix}} = \frac{799.5}{935} = 0.855$$

$$\frac{P_{2'}}{P_{t2'}} = 0.5785$$

and the total pressure at the main turbine is:

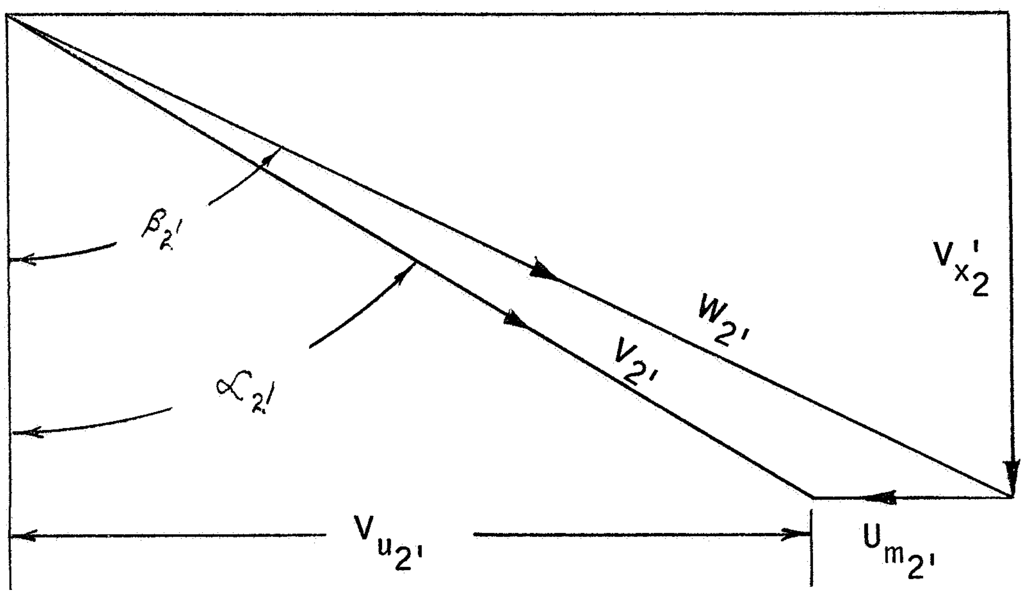
$$P_{t2'} = \frac{45}{0.5785} = 78 \text{ psia } (53.78 \text{ N/cm}^2)$$

2. Inducer Turbine Design Point

The gas conditions at the exit of the main turbine will be the inlet conditions for the low-speed inducer turbine. These conditions can be summarized as follows:

$$T_{t2'} = 935°\text{R } (519.4°\text{K})$$

$$P_{t2'} = 78 \text{ psia } (53.78 \text{ N/cm}^2)$$



$\alpha_{2'}$	58.6^0	
$\beta_{2'}$	64.0^0	
$V_{2'}$	4862 FT/SEC	(1482 m/s)
$V_{x_{2'}}$	2535 FT/SEC	(772.7 m/s)
$V_{u_{2'}}$	4149 FT/SEC	(1264.6 m/s)
$W_{2'}$	5782 FT/SEC	(1762.4 m/s)
$U_{m_{2'}}$	1048 FT/SEC	(319.4 m/s)

Figure 70. Main Turbine Exit Velocity Diagram

$$\dot{W} = 6.16 \text{ lb/sec } (2.79 \text{ kg/s})$$

$$V_{2'} = 4862 \text{ ft/sec } (1482 \text{ m/s})$$

$$\alpha_{2'} = 58.6° \ (1.0226 \text{ rad})$$

At the design point, the inducer turbine is required to operate at 11,600 rpm (1214.7 rad/s) and produce 348 shp (260 kw). Subsequent inducer analysis led to the revision of these requirements; however, the original conservative turbine conditions were left unchanged.

3. Inducer Turbine Fluid Dynamic Design

a. Turbine Power

Turbine total enthalpy drop can be calculated from the power requirement

$$\Delta H = \frac{550 \text{ shp}}{\dot{W} \ J}$$

$$= \frac{(550)(348)}{(6.16)(778.2)} = 39.93 \text{ Btu/lb } (92{,}815 \text{ J/kg})$$

and the change in the tangential component of velocity is given by

$$\Delta V_u = \frac{\Delta H \ J \ g}{U_m}$$

$$\Delta V_u = \frac{(39.93)(778.2)(32.174)}{528} = 1893.5 \text{ ft/sec } (577.14 \text{ m/s})$$

b. Turbine Stator

Assuming the stator exit angle to be $\alpha_1 = 18$ degrees and the velocity coefficient $K_n = 0.9$, the velocity leaving the stator is

$$V_1 = K_n V_0$$

$$= 0.9(4862) = 4375.8 \text{ ft/sec } (1333.7 \text{ m/s})$$

A low value of velocity coefficient was selected to account for flow losses in the impulse low aspect ratio blading. The selection of K_n will be verified subsequently through blade loss analysis.

The axial and tangential velocity components at the inlet to the rotor are:

$$V_{x1} = V_1 \cos \alpha_1 = 4375.8 \ (0.95106) = 4161.6 \text{ ft/sec } (1268.5 \text{ m/s})$$

$$V_{u1} = V_1 \sin \alpha_1 = 4375.8\ (0.30902) = 1352.2 \text{ ft/sec } (412.15 \text{ m/s})$$

and the relative velocity W_1 is

$$W_1 = [V_{x1}^2 + (V_{u1} - U_m)^2]^{1/2}$$

$$W_1 = [(4161.6)^2 + (1352.2 - 528)^2]^{1/2} = 4242.4 \text{ ft/sec } (1293.1 \text{ m/s})$$

Now, the gas angle at the rotor inlet can be calculated

$$\cos \beta_1 = \frac{V_{x1}}{W_1} = \frac{4161.6}{4242.4} = 0.9810$$

$$\beta_1 = 11°12'$$

The static temperature at the stator exit is

$$T_1 = T_{t1} - \frac{V_1^2}{2\ g\ J\ C_p} = 935 - 110 = 825°\text{R } (458.3°\text{K})$$

Assuming no static pressure change in the impulse type stator, the density at its exit is

$$\rho_1 = \frac{144\ P_1}{R\ T_1} = \frac{(144)(45)}{(766.4)(825)} = 0.01025 \text{ lb/ft}^3\ (0.1642 \text{ kg/m}^3)$$

The static-to-total temperature ratio is

$$\frac{T_1}{T_{t1}} = \frac{825}{935} = 0.8824$$

and the corresponding pressure ratio is

$$\frac{P_1}{P_{t1}} = 0.644$$

then, the total pressure at the stator exit becomes

$$P_{t1} = \frac{45}{0.644} = 69.9 \text{ psia}$$

The stator throat area required is

$$A_1 = \frac{144\ \dot{W}}{\rho_1\ V_1} = \frac{(144)(6.16)}{(0.01025)(4375.8)}$$

$$A_1 = 19.8\ \text{in.}^2\ (0.01277\ \text{m}^2)$$

If 59 blades are used, then the throat width at the mean radius is found to be

$$d_1 = 0.472\ \text{in.}\ (0.01199\ \text{m})$$

and the blade height is

$$h_1 = \frac{A_1}{d_1\ n_1}, \quad \text{where } n_1 = \text{no. of blades}$$

$$h_1 = \frac{19.8}{(0.472)(59)} = 0.711\ \text{in.}\ (1.806\ \text{cm})$$

c. Turbine Rotor

Assuming that the relative velocity does not change, in the wheel,

$$W_2 = W_1 = 4242.4\ \text{ft/sec}$$

the exit whirl velocity required is

$$V_{u2} = \Delta V_u - V_{u1}$$

$$= 1893.5 - 1352.2 = 541.3\ \text{ft/sec}\ (165\ \text{m/s})$$

Now, the relative gas angle at exit is

$$\sin \beta_2 = \frac{U_m + V_{u2}}{W_2} = \frac{528 + 541.3}{4242.4} = 0.2505$$

$$\beta_2 = 14°30'$$

The axial velocity component is

$$V_{x2} = W_2 \cos \beta_2 = (4242.4)(0.9682)$$

$$V_{x2} = 4107.5\ \text{ft/sec}\ (1252\ \text{m/s})$$

and the absolute velocity at exit is

$$V_2 = (V_{x2}^2 + V_{u2}^2)^{1/2}$$

$$= [(4107.5)^2 + (541.3)^2]^{1/2} = 4143 \text{ ft/sec}$$
$$(1262.8 \text{ m/s})$$

The complete velocity diagram at mean radius is shown on Figure No. 71. It becomes immediately evident from Figure No. 71 thata very low blading efficiency can be expected because the gas angles are not nearly optimum.

The total temperature at the rotor exit is

$$T_{t2} = T_{t1} - \frac{\Delta H}{C_p}$$

$$= 935 - \frac{39.93}{3.483} = 923.5°R \ (513.1°K)$$

and the static temperature is

$$T_2 = T_{t2} - \frac{V_2^2}{2 \ g \ J \ C_p}$$

$$T_2 = 923.5 - \frac{4143^2}{2(32.174)(778.2)(3.483)} = 825°R \ (458.3°K)$$

and the temperature ratio is

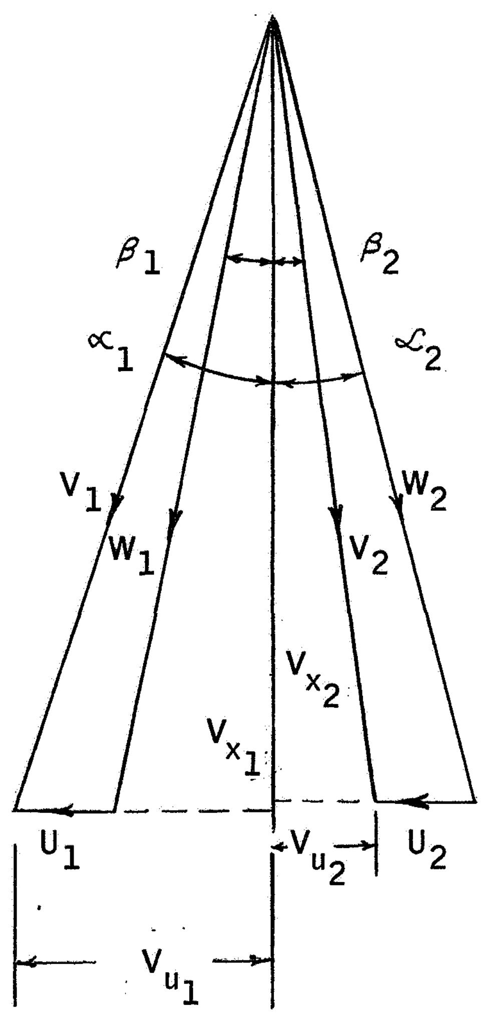
$$\frac{T_1}{T_{t1r}} = \frac{825}{928.2} = 0.8888$$

From this temperature ratio, the total relative pressure at the rotor inlet can be calculated.

$$\frac{P_1}{P_{t1r}} = 0.6625; \quad P_{t1r} = \frac{45}{0.6625} = 67.9 \text{ psia } (46.82 \text{ N/cm}^2)$$

Assuming adiabatic flow through the rotor,

$$T_{t2r} = T_{t1r} = 928.2°R \ (515.67°K)$$



PARAMETER	
α_1	18^0
β_1	11.12^0
α_2	7.5^0
β_2	14.5^0
$U_{1,2}$	528 FT/SEC (160.9 m/s)
V_1	4375.8 FT/SEC(1333.7 m/s)
V_{x_1}	4161.6 FT/SEC (1268 m/s)
V_{u_1}	1352.2 FT/SEC(412.15 m/s)
W_1	4242.4 FT/SEC(1293.1 m/s)
V_2	4143 FT/SEC (1262.8 m/s)
V_{x_2}	4107.5 FT/SEC(1252 m/s)
V_{u_2}	541.3 FT/SEC (165 m/s)
W_2	4242.4 FT/SEC(1293.1 m/s)

Figure 71. - Inducer Turbine Velocity Diagram at Mean Radius.

and because $W_2 = W_1$, it follows that the static temperatures at inlet and exit are equal

$$T_2 = T_1 = 825°R\ (458.3°K)$$

Assuming now that the velocity coefficient for this rotor blade is

$$K_r = 0.95$$

the ideal velocity at the exit is

$$W_{2i} = \frac{W_2}{K_r} = \frac{4242.4}{0.95} = 4465.7 \text{ ft/sec } (1361.1 \text{ m/s})$$

and the isentropic temperature ratio at exit is

$$T_{2i} = T_{t1r} - \frac{W_{2i}^2}{2\ g\ J\ C_p}$$

$$T_{2i} = 928.2 - \frac{(4465.7)^2}{2(32.174)(778.2)(3.483)} = 813.9°R\ (452.2°K)$$

$$\frac{T_{2i}}{T_{t1r}} = \frac{813.9}{928.2} = 0.8769$$

From this temperature ratio, the static pressure at the exit can be calculated

$$\frac{P_2}{P_{t1r}} = 0.6315$$

$$P_2 = 0.6315(67.9) = 42.9 \text{ psia } (29.58 \text{ N/cm}^2)$$

Now, the static density at the rotor exit is

$$\rho_2 = \frac{144\ P_2}{R\ T_2}$$

$$= \frac{(144)(42.9)}{(766.4)(825)} = 0.00977 \text{ lb/ft}^3\ (0.1565 \text{ kg/m}^3)$$

and the rotor throat area is

$$A_2 = \frac{\dot{W}}{\rho_2\ W_2} = \frac{(144)(6.16)}{(0.00977)(4242.4)} = 21.4 \text{ in.}^2\ (0.01381 \text{ m}^2)$$

Assuming 66 blades, the throat width at the mean diameter is estimated from the blade layout to be

$$d_2 = 0.415 \text{ in. } (1.054 \text{ cm})$$

and the blade height is

$$h_2 = \frac{A_2}{d_2\ n_2} = \frac{21.4}{0.415(66)} = 0.781 \text{ in. } (1.984 \text{ cm})$$

d. Stage Performance at the Design Point

The flow parameter of the inducer turbine with reference to inlet conditions is

$$\frac{\dot{W}\ \sqrt{T_{t0}}}{P_{t0}} = \frac{6.16\ \sqrt{935}}{78} = 2.415$$

The total-to-static pressure ratio is

$$PRs = \frac{P_{t0}}{P_2} = \frac{78}{42.9} = 1.818$$

The isentropic enthalpy drop is

$$\Delta H_i = C_p\ T_{t0}\ [1 - (1/PRs)^{\frac{\gamma-1}{\gamma}}]$$

$$= (3.483)(935)[1 - (1/1.818)^{\frac{0.396}{1.396}}] = 508.4 \text{ Btu/lb } (1{,}181{,}748 \text{ J/kg})$$

The spouting velocity is

$$C_o = (2\ g\ J\ \Delta H_i)^{1/2}$$

$$= [2(32.174)(778.2)(508.4)]^{1/2} = 5045.6 \text{ ft/sec } (1537.9 \text{ m/s})$$

Now, the velocity ratio is

$$\frac{U_m}{C_o} = \frac{528}{5045.6} = 0.1046$$

The static efficiency is

$$\eta_s = \frac{\Delta H}{\Delta H_i} = \frac{39.93}{508.4} = 7.85\%$$

4. Turbine Blade Profile

a. Stator Blade Profile

Stator inlet angle is determined from the exit velocity diagram of the main turbine

$$\alpha_0 = 58.6°$$

The stator exit gas angle is 18 degrees. The deviation of 6 degrees was selected upon the basis of Reference 13, which results in a blade exit angle of 24 degrees. It is essentially a turning vane having a camber angle of

$$\theta = \alpha_0 + \alpha_1 + \delta_1 = 58.6 + 18 + 6 = 82.6°$$

A relatively high blade solidity of 1.6 was selected to avoid possible blade stalling in the impulse type stator.

The stator inlet height is matched to the main turbine second-stage rotor configuration as shown on Figure No. 72. The flow channel was carefully laid out to provide a smooth area transition from the inlet to the exit. Figure No. 73 is a sketch of the stator profile while the side view of the flow passage is shown on Figure No. 72.

b. Rotor Blade Profile

From the velocity diagram, Figure No. 71, the gas turning angle is

$$\theta = \beta_1 + \beta_2 = 11.2° + 14.5° = 25.7°$$

To satisfy rotor throat size requirements for constant height, unflared blades, it was necessary to provide a relatively thick trailing edge (r_t = 0.03-in., 0.0762 cm). For this thick trailing edge, the deviation angle was estimated as follows:

$$\text{Cos } \beta_{2b} = \frac{d_2}{s - 2r_t}$$

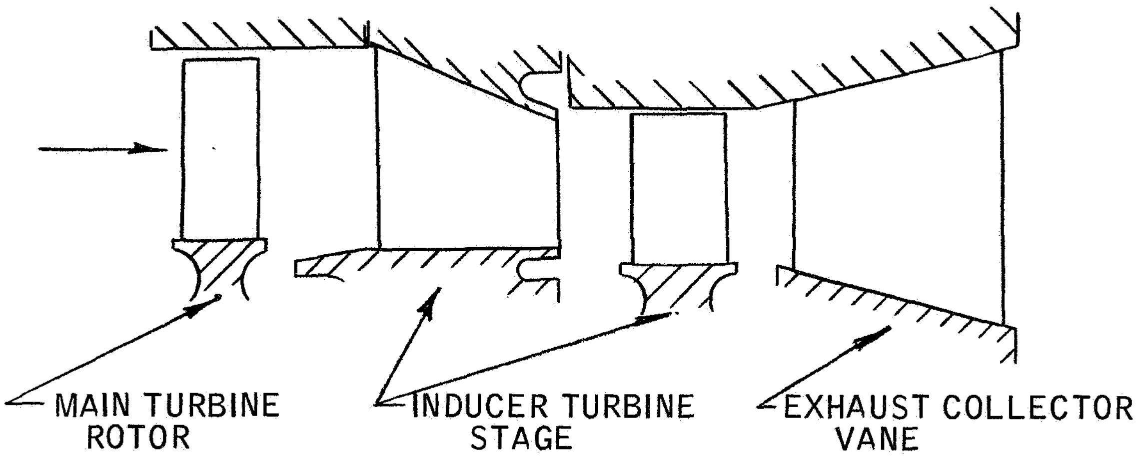


Figure 72. - Turbine Annulus Flow Passage.

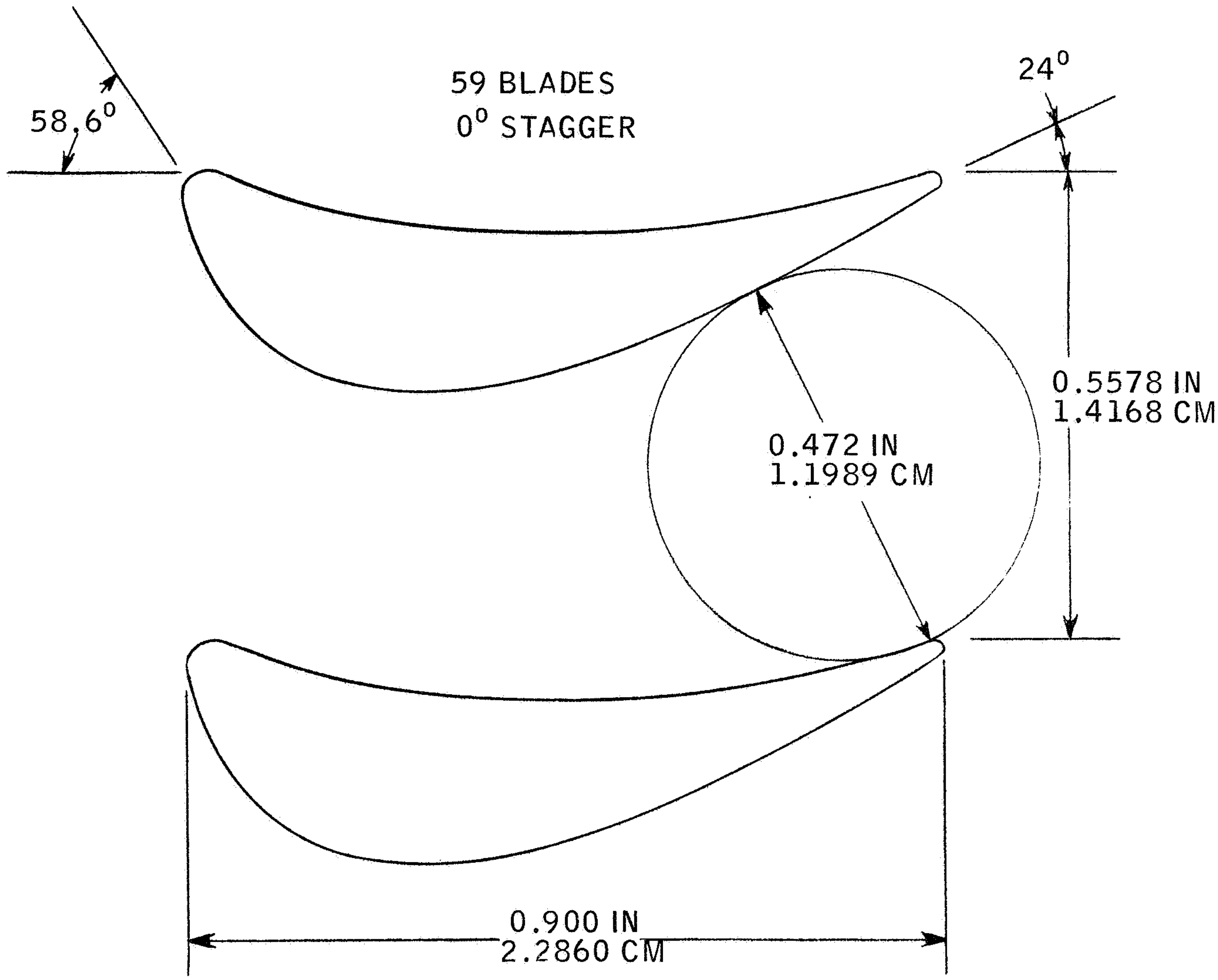


Figure 73. - Stator Blade Profile.

where d_2 = rotor blade opening = 0.415 in. (1.054 cm)

s = pitch at mean radius = 0.497 in. (1.262 cm)

β_{2b} = blade exit angle

$$\cos \beta_{2b} = \frac{0.415}{0.497 - 0.06} = 0.951$$

$$\beta_{2b} = 18°$$

and the deviation angle is

$$\delta_2 = 18° - 14.50° = 3.5°$$

In addition to the deviation correlation, an induced angle of 4 degrees was used to correct for streamline curvature at the inlet.

The blade camber angle is

$$\theta = \beta_1 + \beta_2 + \Delta\theta_1 + \delta_2$$

$$\theta = 11.2° + 14.5° + 3.5° + 4.0° = 33.2°$$

For this very low camber angle and low resultant blade loading, the blade solidity of 1.0 was selected, based upon References 14 and 15.

The rotor blade profile and the associated flow passage in the tangential plane are shown on Figure No. 74. The unconventional nature of this design is a result of a high inlet Mach number and the low inducer horsepower.

c. Exhaust Collector Vane

The exhaust collector used on the technology turbopump was modified to accommodate the inducer turbine bearing and to facilitate the assembly of the inducer turbine.

The bearing support incorporates 24 vanes designed to accept the turbine flow and increase its tangential velocity component to provide for more efficient evacuation of the flow through the two tangential outlets.

Vanes were designed for a small amount of diffusion to avoid flow separation. A high pressure recovery factor would have required a larger area ratio and a greater diffuser length. These desirable features could not be incorporated into the existing collector because of the cost and time restrictions. Figure No. 75 is a sketch of the vane profile.

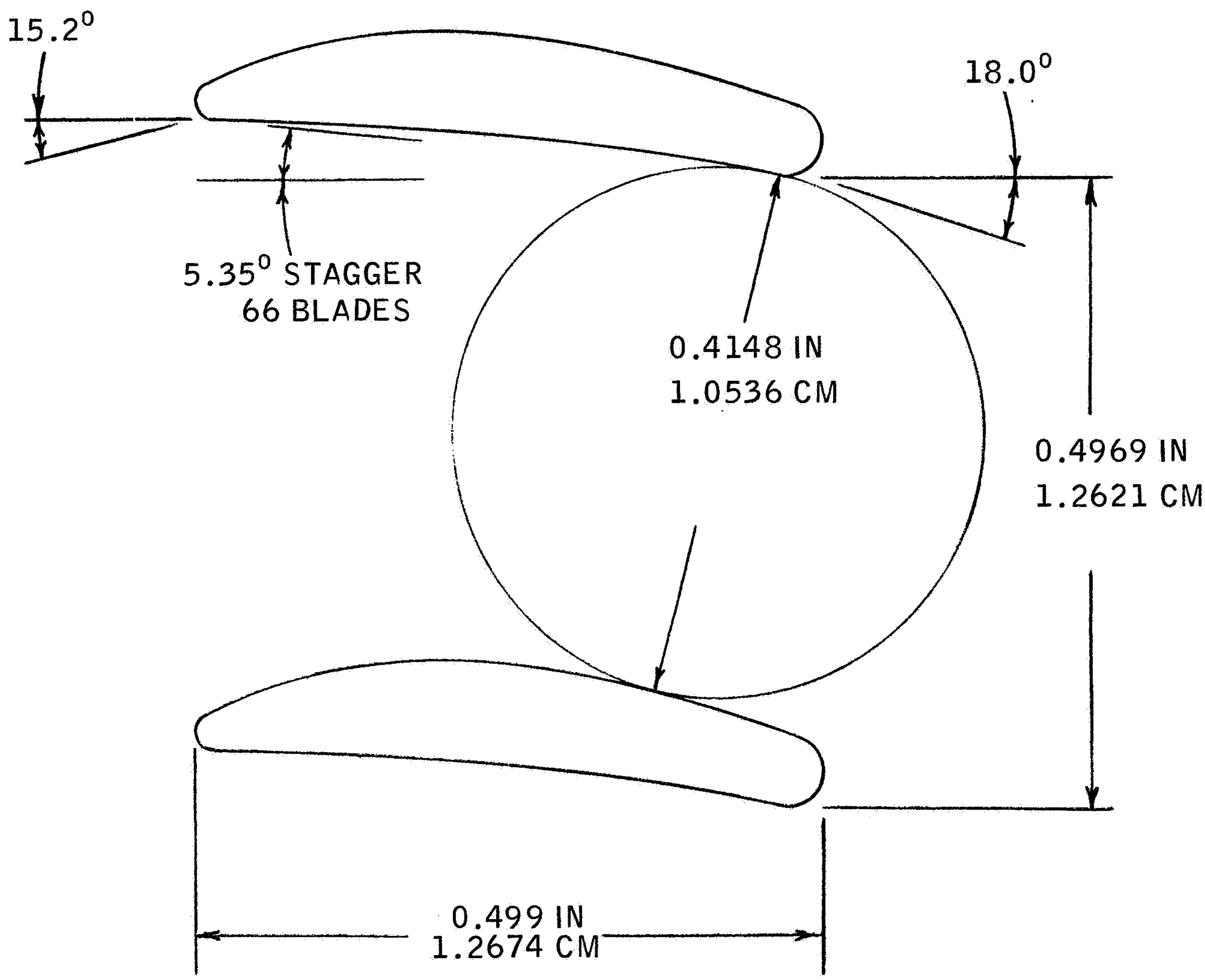


Figure 74. - Rotor Blade Profile, 66 Blades.

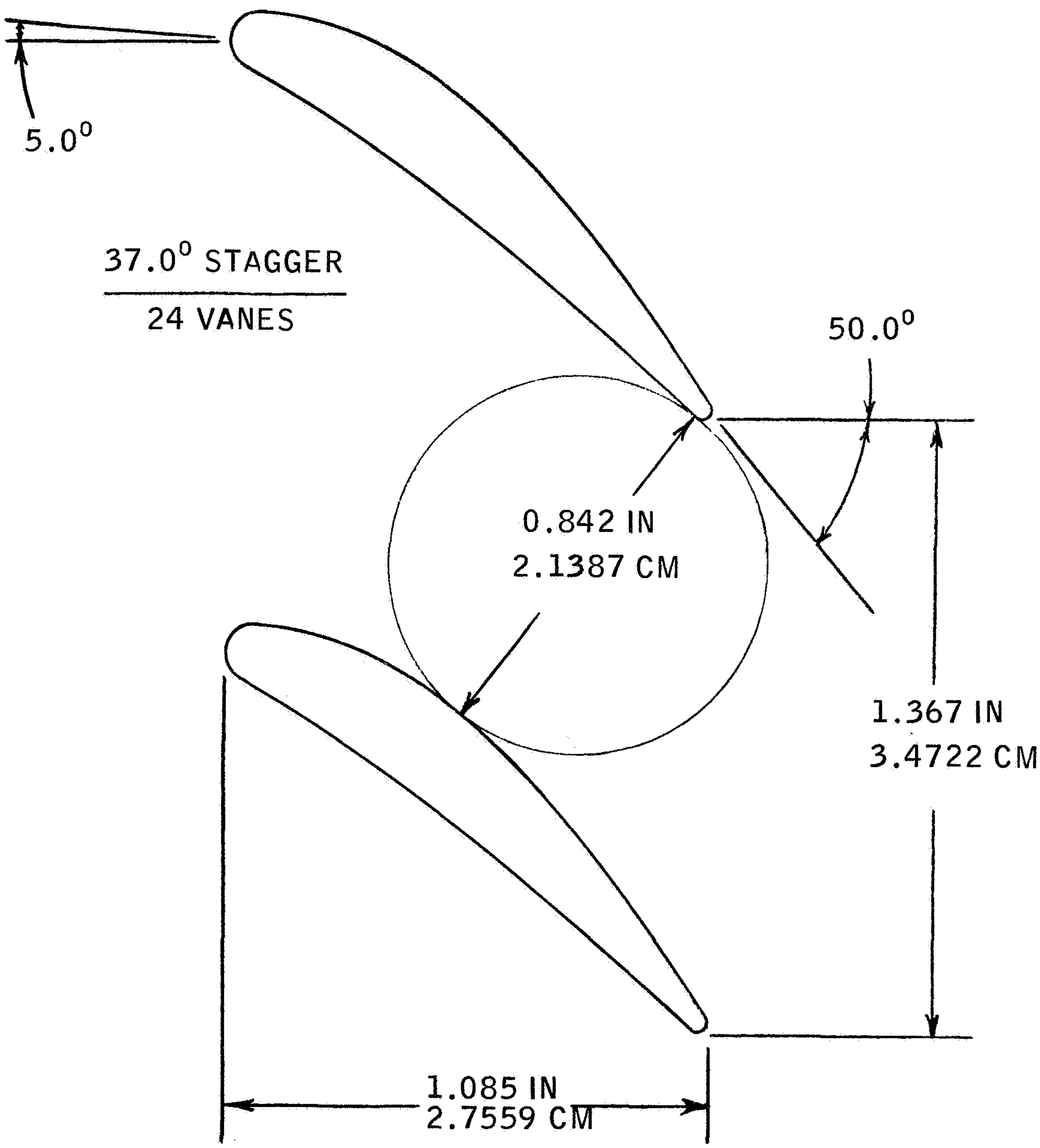


Figure 75. - Exhaust Collector Vane Profile.

5. Turbine Blade Loss Analysis

a. Soderberg's Method

A blade loss analysis can be made after the blade profile configuration is established. Here, Soderberg's method will be used to verify the previously estimated blading efficiency.

Soderberg has correlated the losses upon the basis of solidity, Reynolds number, aspect ratio, thickness ratio, and gas deflection. Figure No. 76 shows the nominal loss coefficient ξ' plotted in relationship to gas turning angle $\varepsilon = \alpha_1 + \alpha_2$ for an aspect ratio h/b of 3:1 and a Reynolds number of 10^5 (Ref. 16, page 86). For aspect ratios other than 3:1, Soderberg recommends the correction

$$\xi'' = (1 + \xi')(0.975 + 0.075\ b/h) - 1$$

where $\xi' = f(\varepsilon)$ is shown plotted on Figure No. 76. For Reynolds numbers other than 10^5,

$$\xi''' = (10^5/Re)^{0.25}\ \xi''$$

where Re is the Reynolds number based upon throat hydraulic diameter

$$D_h = \frac{2\ d\ h}{d + h}$$

Thus, the total loss coefficient is

$$\xi''' = (10^5/Re)^{0.25}\ [(1 + \xi')(0.975 + 0.075\ b/h) - 1]$$

To correct for tip clearance losses, the calculated stage efficiency is multiplied by the ratio of blade annulus area to total annulus area, including leakage space.

Knowing the loss coefficients for the stator and rotor, the total-to-static efficiency of the stage is

$$\eta_s = \left(\frac{1}{1 + \left[\frac{\xi_R'''\ W_2^2}{2} + \left(\frac{T_2}{T_1}\right) \frac{\xi_N'''\ V_1^2}{2} + \frac{V_2^2}{2} \right] / \Delta H\ \ J\ g} \right) \left(\frac{A_a}{A_a + A_c} \right)$$

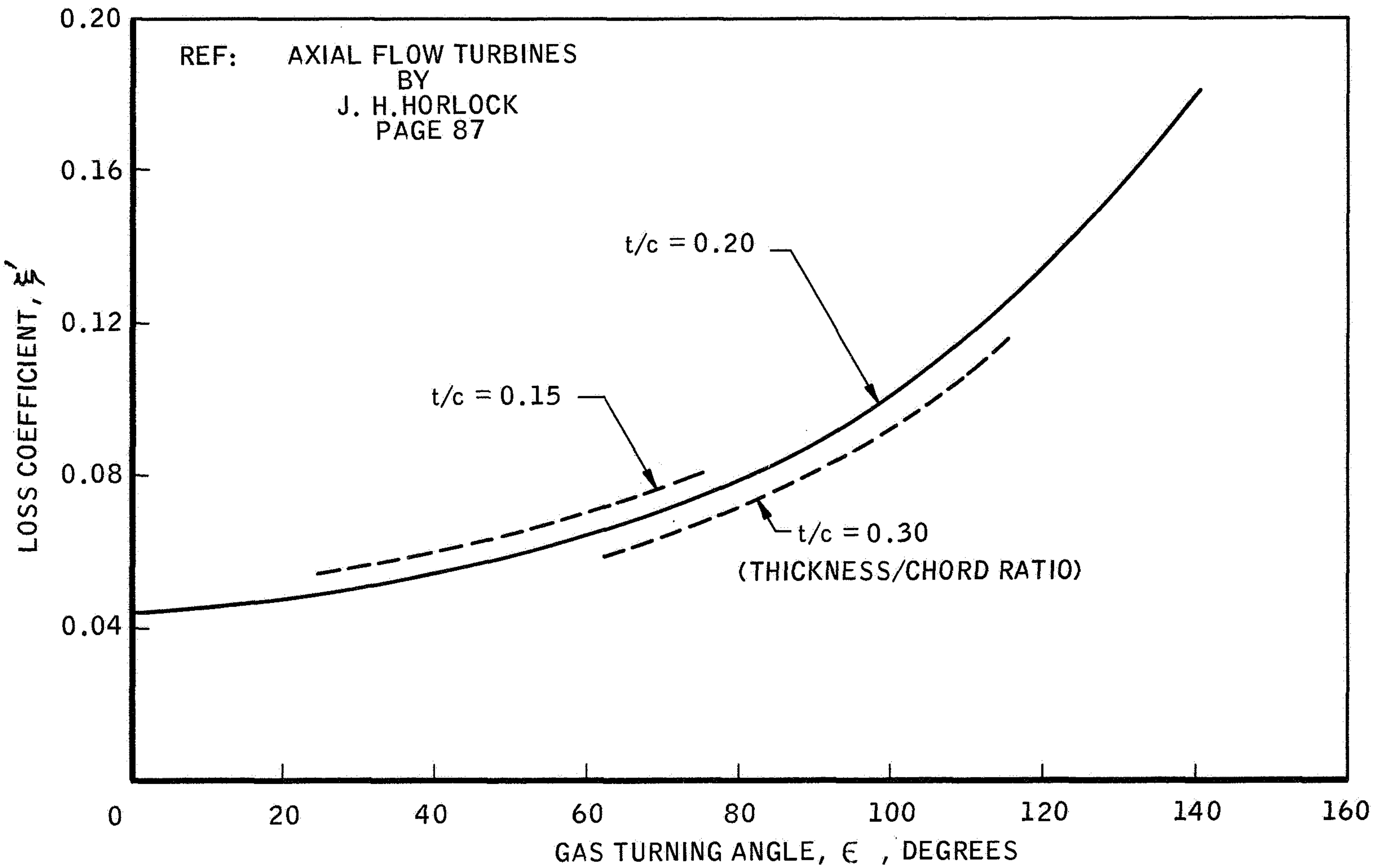


Figure 76. - Loss Coefficient vs Gas Turning Angle.

b. Stator Loss Coefficient

Summary of stator blade data:

Blade height at the throat	h_1 = 0.711 in. (1.306 cm)
Mean blade height	$\bar{h}$ = 0.860 in. (2.184 cm)
Axial chord	b = 0.900 in. (2.286 cm)
Throat opening	d_1 = 0.472-in. (1.1989 cm)
Throat area	A_1 = 19.8-in.^{2} (0.012774 m^2)
Pitch at mean radius	s = 0.5578-in. (1.4168 cm)
Thickness to chord ratio	t/c = 0.228
Gas inlet angle	α_0 = 58.6°
Gas exit angle	α_1 = 18°
Exit velocity	V_1 = 4375.8 ft/sec (1333.7 m/s)
Number of blades	n = 59
Absolute viscosity of gas	μ = 0.862 x 10^{-5} lb/ft-sec (1.2828 x 10^{-5} Ns/m^2)

From Figure No. 76 for ε = 76.6°, ξ' = 0.074.

The hydraulic diameter is

$$D_h = \frac{2\ d_1\ h_1}{d_1 + h_1} = \frac{(2)(0.472)(0.711)}{(12)0.472 + 0.711}$$

$$D_h = 0.04728 \text{ ft } (1.441 \times 10^{-2} \text{ m})$$

and the Reynolds number based upon stator throat conditions is

$$Re = \frac{D_h\ V_1\ \rho_1}{\mu}$$

$$= \frac{(0.04728)(4375.8)(0.01025)}{(0.862)(10^{-5})}$$

$$Re = 245{,}981$$

$$\xi_n''' = \left(\frac{10^5}{245,981}\right)^{0.25} [(1 + 0.074)(0.975 + 0.075 \frac{0.9}{0.86}) - 1]$$

$$\xi_n''' = 0.105$$

c. Rotor Loss Coefficient

Blade height	h_2 = 0.781-in. (1.984 cm)
Axial chord	b = 0.499-in. (1.267 cm)
Throat opening	d_2 = 0.4148-in. (1.054 cm)
Throat area	A_2 = 21.4-in.^{2} (1.381 x 10^{-2} m^2)
Pitch at mean radius	s = 0.4969 in. (1.262 cm)
Thickness to chord ratio	t/c = 0.16
Gas inlet angle	β_1 = 11.2-degrees
Gas exit angle	β_2 = 14.5-degrees
Exit velocity	V_2 = 4143 ft/sec (1263 m/s)
Number of blades	n = 66
Absolute viscosity of gas	μ = 0.862 x 10^{-5} lb/ft-sec (1.2828 x 10^{-5} Ns/m^2)

From Figure No. 76 for ε = 25.7-degrees, ξ' = 0.054

The hydraulic diameter is

$$D_h = \frac{2\, d_2\, h_2}{d_2 + h_2} = \frac{(2)(0.4148)(0.781)}{(12)(0.4148 + 0.781)} = 0.0452 \text{ ft } (1.376 \text{ m})$$

and the Reynolds number based upon rotor throat conditions is

$$Re = \frac{D_h\, V_2\, \rho_2}{\mu_2} = \frac{(0.0452)(4143)(0.00977)}{(0.862)(10^{-5})}$$

$$Re = 212,247$$

$$\xi_R''' = \left(\frac{10^5}{212,247}\right)^{0.25} [(1 + 0.054)(0.975 + 0.075 \frac{0.499}{0.781}) - 1]$$

$$\xi_R''' = 0.065$$

d. Stage Efficiency

The stage efficiency can now be calculated

$T_2 = T_3$

Tip clearance is 0.045-in. and $\frac{A_a}{A_a + A_c} = \frac{25.897}{27.490} = 0.941$

$$\eta_s = 0.941 \left\{ \frac{1}{1 + \left[\frac{(0.065)(4242.4)^2}{2} + \frac{(0.105)(4375.8)^2}{2} + \frac{(4143)^2}{2} \right] / (39.93)(778.2)(32.174)} \right\}$$

$\eta_s = 8.4\%$

This prediction agrees quite well with the previously estimated efficiency of 7.85%. However, Soderberg's method neglects the effect of trailing edge thickness and it implies that the degree of reaction is unimportant as long as the optimum blade solidity is used. In view of these considerations, it might be expected that the actual efficiency will be somewhat lower than predicted.

B. TURBINE OFF-DESIGN PERFORMANCE PREDICTION

Inducer turbine off-design performance curves are required so that the equilibrium running line for the inducer spool can be determined and related to the main spool operating characteristics. The equilibrium running line is determined by a computer program for predicting the characteristics of the twin-spool turbopump. This program requires flow parameter $(\dot{W}\sqrt{T_{t0}})/P_{t0}$ versus pressure ratio (PR) and efficiency (η_s) versus velocity ratio (U_m/C_o) curves.

For single-stage, axial-flow turbines, rotational speed is not expected to have an appreciable affect upon the pressure ratio-mass flow relationship. For this reason, in Figure No. 77, the flow parameter-pressure ratio relationship is represented by a single curve, which is referred to the total conditions at the turbine inlet. At the design point, the flow parameter takes the value

$$\frac{\dot{W}\sqrt{T_{t0}}}{P_{t0}} = \frac{6.16\sqrt{935}}{78} = 2.415 \text{ (1.184 SI units)}$$

and the static pressure ratio at this point is

$$PR = \frac{P_{t0}}{P_2} = \frac{78}{42.9} = 1.818$$

where P_2 is the static pressure at the rotor exit.

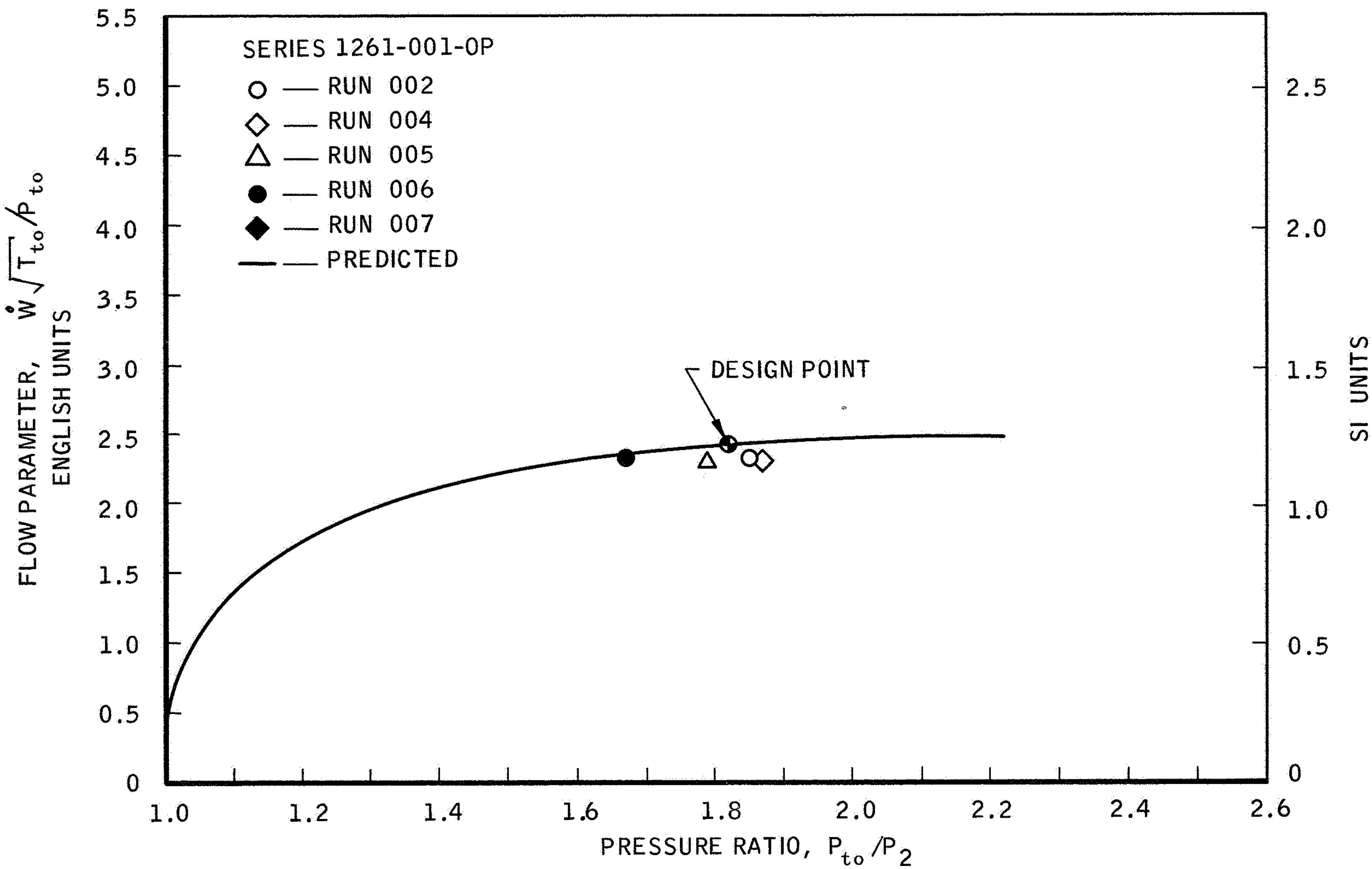


Figure 77. Flow Parameter vs Pressure Ratio (Inducer Turbine)

For the turbine stator at choking conditions, the flow parameter will become

$$\left(\frac{\dot{W}_t \sqrt{T_{t0}}}{P_{t0}}\right)_{choking} = \left(\frac{\gamma g}{R}\right)^{1/2} \left(\frac{2}{\gamma+1}\right)^{\left(\frac{\gamma+1}{2(\gamma-1)}\right)} \frac{P_{t1}}{P_{t0}} A_1$$

where P_{t1} is the total pressure at the stator throat and A_1 is the throat area

$$A_1 = 19.8 \text{ in.}^2 \ (0.01277 \text{ m}^2)$$

$$\frac{P_{t1}}{P_{t0}} = \frac{69.9}{78} = 0.8962$$

for hydrogen gas

$$\left(\frac{\gamma g}{R}\right)^{1/2} \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} = \left[\frac{(1.396)(32.174)}{766.4}\right]^{1/2} \left[\frac{2}{2.396}\right]^{\frac{2.396}{2(0.396)}}$$

$$= 0.1402 \ (0.07789 \ \sqrt{^\circ K}/s)$$

$$\left(\frac{\dot{W} \sqrt{T_{t0}}}{P_{t0}}\right)_{choking} = (0.1402)(0.8962)(19.8) = 2.488 \ (1.220 \text{ SI units})$$

Figure No. 78 is a familiar plot of static efficiency in terms of velocity ratio U_m/C_o. At the design point, this efficiency is estimated to be approximately 7.85% for a velocity ratio of 0.1046.

C. TURBINE TEST DATA ANALYSIS

The twin-spool turbopump was tested over a wide pump operating range to determine the effect of the inducer upon the pump performance. Room temperature hydrogen was used as a turbine drive gas although the inducer turbine blading was sized for hot hydrogen operation.

Turbine instrumentation, which is described separately in this report, allowed the determination of over-all turbine performance only. No pressure or temperature surveys along the turbine annulus height were made. Main turbine efficiency was calculated using pump horsepower which, in turn, is determined from the pump head and temperature rise. Similarly, inducer turbine efficiency relies upon the inducer horsepower. As a result, any inaccuracy in the horsepower calculation is carried over to the turbine

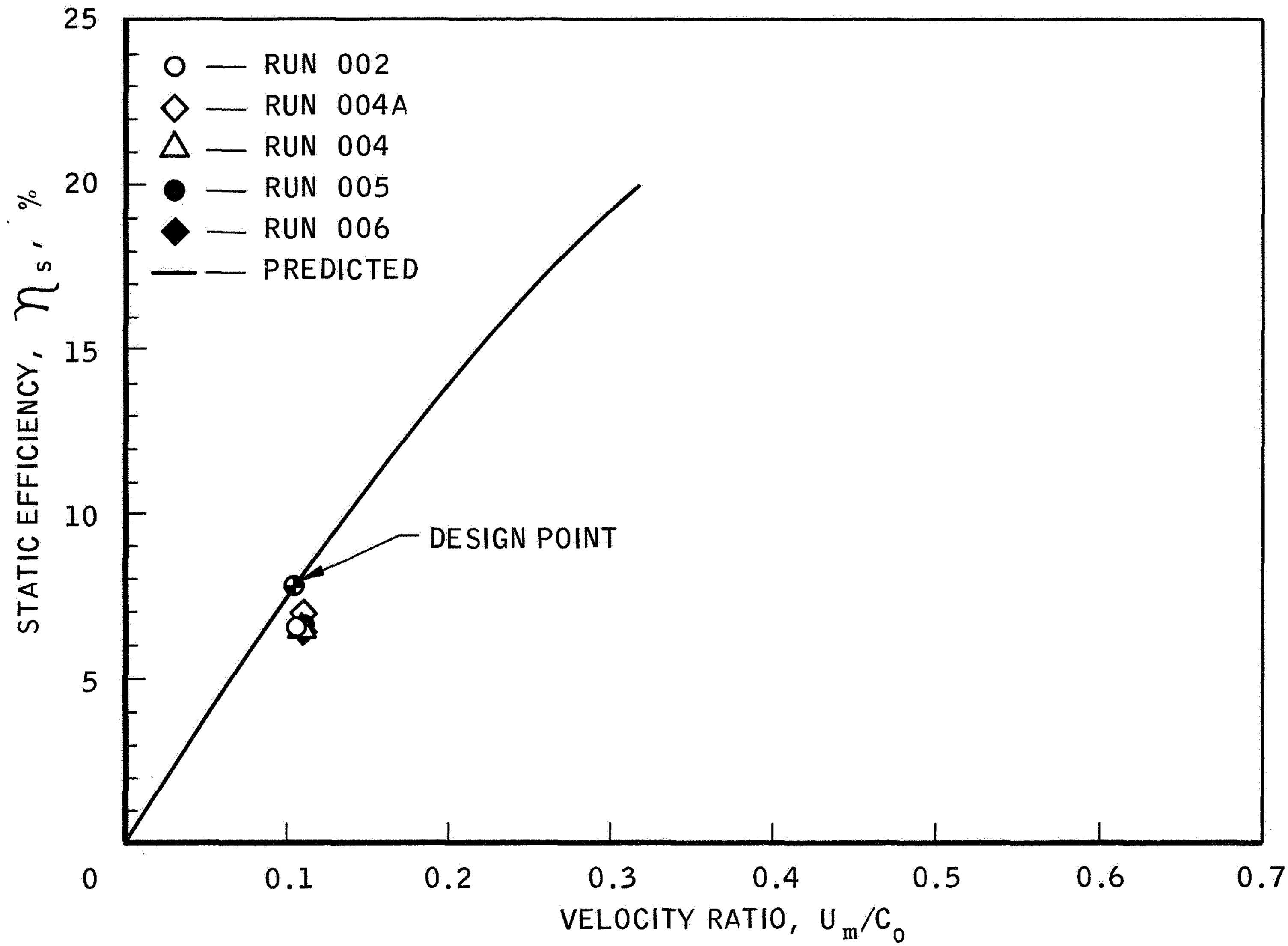


Figure 78. Static Efficiency (Inducer Turbine)

efficiency computation. In particular, the error in the inducer horsepower can be considerable because the temperature rise across the inducer is of the same order of magnitude as the tolerance of the temperature reading.

For the main turbine, the test data covered the range of static pressure ratios from 3.5 to 6 and velocity ratios from 0.10 to 0.19. The data points are shown plotted on Figures No. 68 and No. 69. Generally good agreement is evident between the new test data and the predicted curves. The turbine flow parameter, $\dot{W}\sqrt{T_{t0'}}/P_{t0'}$, was somewhat higher than expected for a room temperature hydrogen gas drive.

The inducer turbine test data ranges over the static pressure ratio of 1.67 to 1.87 at a practically constant velocity ratio. In Figure No. 77, the test points fell slightly below the predicted flow parameter curve. It appears that this was caused by the gas leakage which bypassed the turbine stator. This leakage occurred through the stator labyrinth and the inducer shaft labyrinth.

Turbine static efficiency test data are shown on Figure No. 78. The experimental points agree very well with the design U_m/C_o but the static efficiency is lower than predicted by approximately 1.1 points. Efficiency prediction for a low power turbine such as this is very difficult because the conditions at the turbine inlet are not known to a desirable degree of accuracy. Secondly, it is difficult to account for the effect of gas leakage. Also, the accuracy of the pressure and temperature measurements is difficult to achieve under actual test conditions. As mentioned, the inducer horsepower used in the turbine efficiency calculation is subject to inaccuracy because of the small temperature rise in the inducer. In view of these considerations, the turbine efficiency determined from the experimental data is restricted to an indication of the performance level.

Various size orifices were installed downstream of the exhaust collector to determine the effect of backpressure upon the speed and power split between the main turbine and inducer turbine. Tests No. 5 and No. 6 were conducted using orifices that reduced the effective exhaust duct area by 10% and 20% of the nominal value, respectively. At the nominal operating point, the observed results were approximately as follows:

Exit Area Reduction	Speed Reduction	shp Reduction
10%	2%	6.7%
20%	4%	14.5%

D. CONCLUSIONS

1. The single-stage axial-flow turbine designed to drive the inducer for the twin-spool turbopump feasibility demonstration proved to be a successful concept.

2. Data obtained from the twin-spool turbopump tests indicated that the average turbine efficiency was approximately 6.75%. This shows good agreement with the predicted value of 7.85%.

3. The turbines used in this unit do not require any special controls for safe operation.

4. The low power and speed requirements of the inducer spool as well as the high Mach number at the turbine inlet resulted in an unconventional blading and a low static efficiency.

V. MECHANICAL DESIGN

A. DESCRIPTION

The turbopump configuration used for the Twin-Spool Turbopump feasibility demonstration is a coaxial design which incorporates a low-speed inducer driven by a single-stage impulse turbine. An existing positive NPSP turbopump was modified by incorporating newly-fabricated components to provide for the coaxial configuration shown on Figure No. 79. The assembled Twin-Spool Turbopump mounted into the build-up stand is shown on Figures No. 80, No. 81, and No. 82.

The main turbopump consists of a single-stage centrifugal pump with an integral inducer driven by a two-stage impulse turbine. The turbine is coupled to the pump through a liquid-hydrogen-cooled bearing housing by a hollow shaft.

The low-speed inducer is driven through a single-stage impulse turbine by a solid shaft, which passes through the hollow shaft of the main-stage rotating assembly. Both the inducer and the inducer turbine are supported by liquid-hydrogen-cooled bearings.

Labyrinth seals were placed at the turbine and pump ends of the main shaft to prevent turbine drive gas from entering the main pump inlet. The labyrinths are designed to provide for pressurization of the cavity between the high and low-speed shafts, with a portion of the main-stage bearing coolant flow.

Table III presents geometric data pertinent to the Twin-Spool Turbopump.

B. DESIGN CONDITIONS

Component mechanical design was accomplished using predicted turbopump conditions at the nominal design point. Mechanical design conditions are shown on Table IV. The mechanical design analysis was conducted assuming an overspeed condition (or mechanical design speed) of 115% of the nominal design point speed.

C. STRUCTURAL CRITERIA

Structural design criteria were established at the beginning of component design. The resulting design factors are compatible with values used for design of the main-stage turbopump.

For mechanical design purposes, the following definitions and criteria were applied to the inducer stage components:

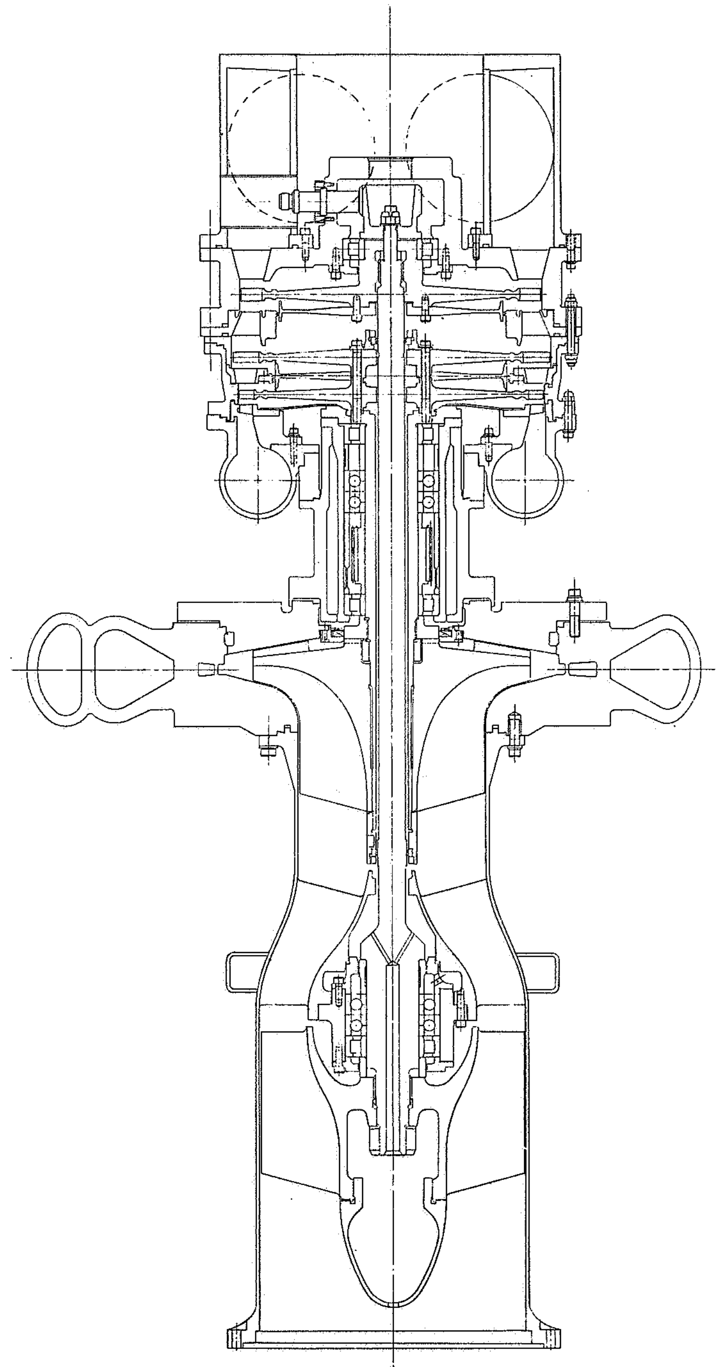


Figure 79. - Twin-Spool Turbopump.

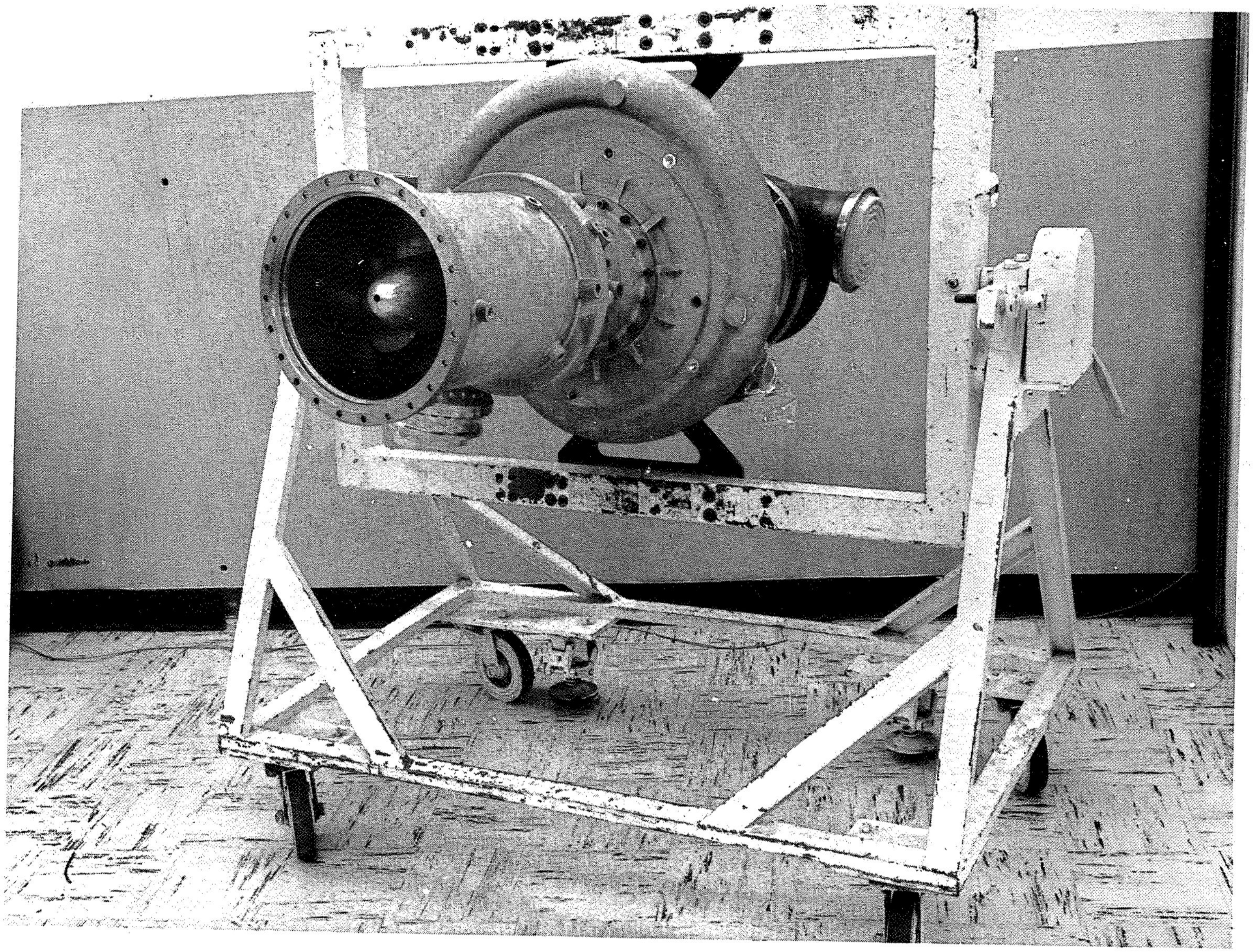


Figure 80. - View of Turbopump Assembly in Build-Up Stand.

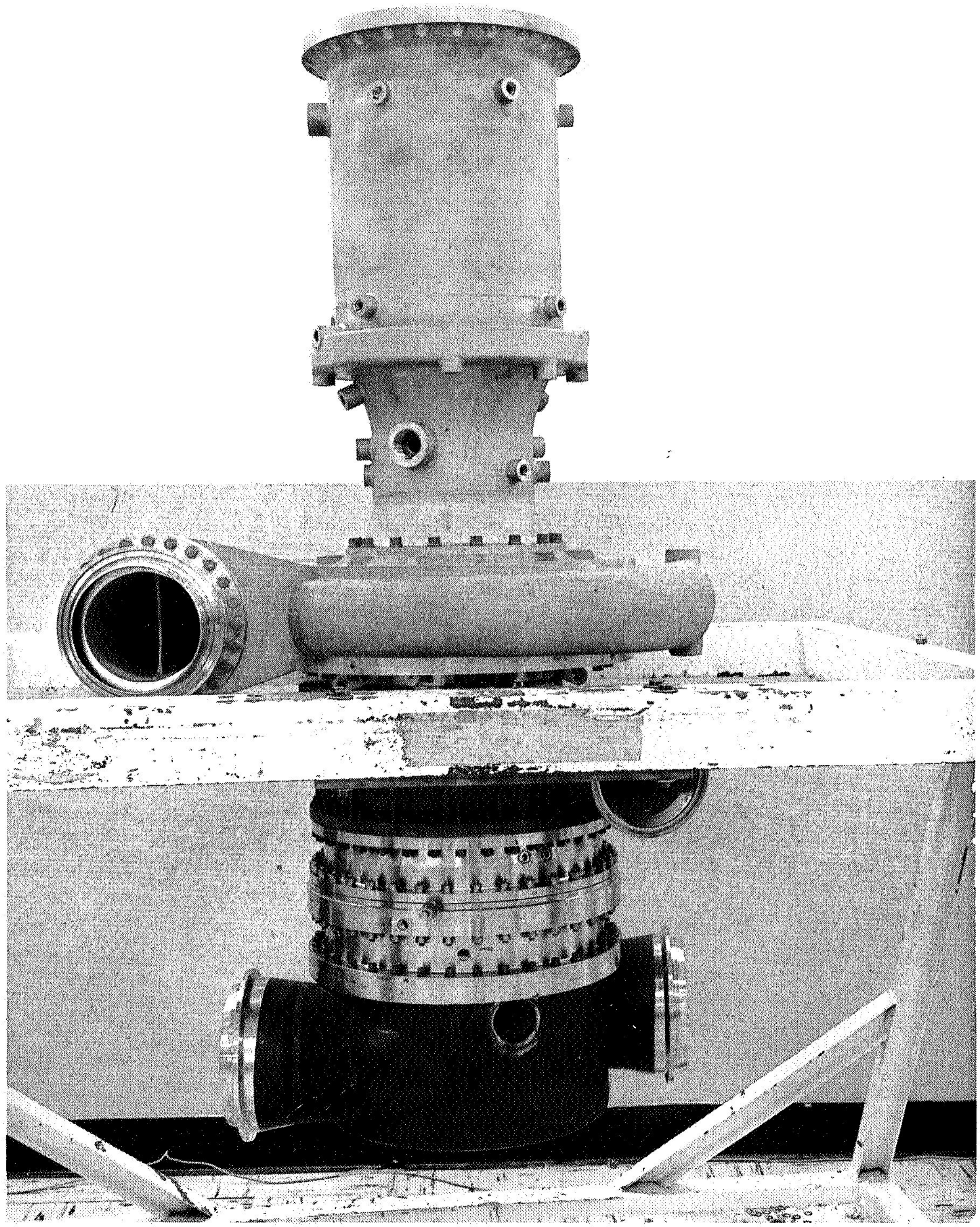


Figure 81. - View of Turbopump Assembly in Build-Up Stand.

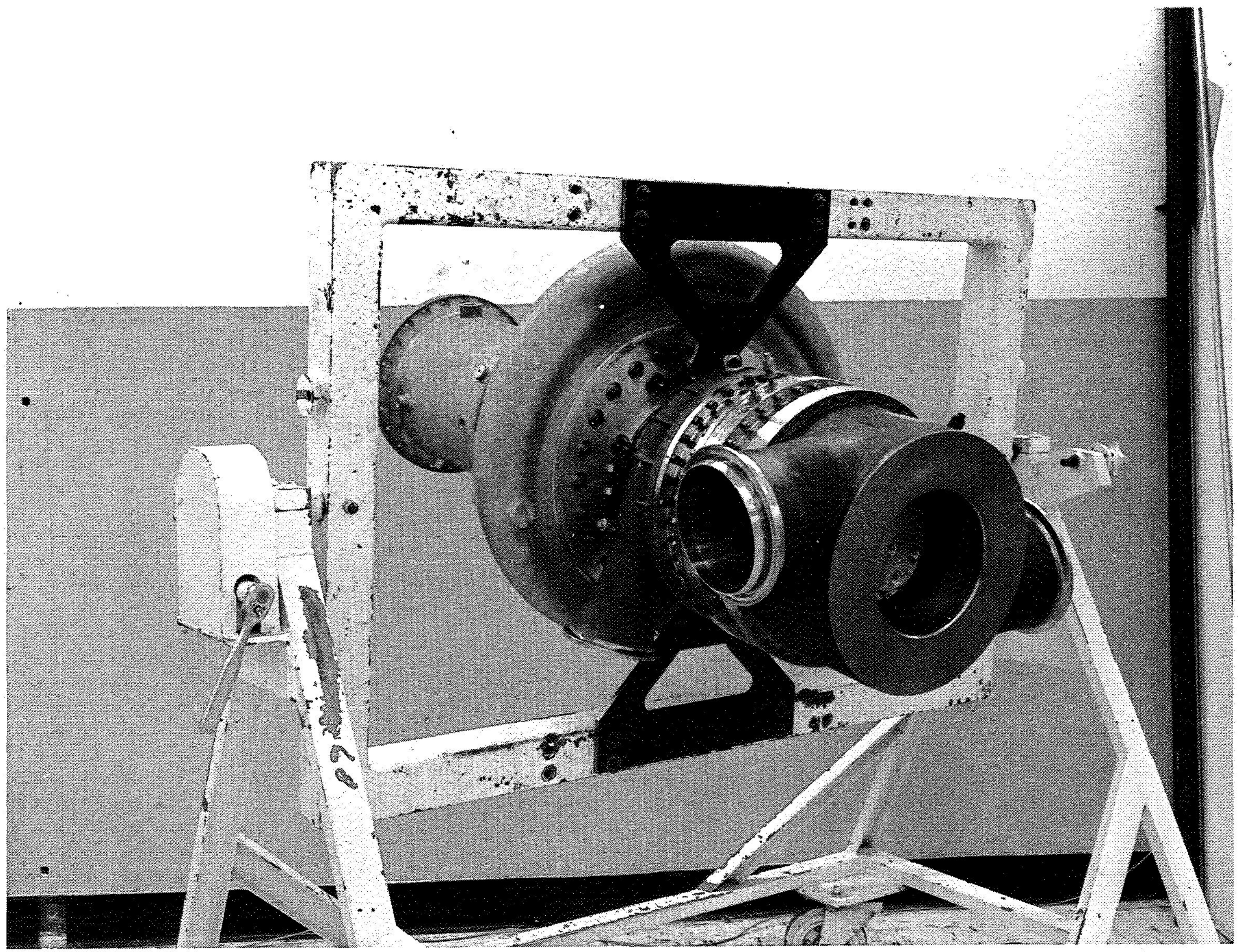


Figure 82. - View of Turbopump Assembly in Build-Up Stand.

TABLE III

TWIN-SPOOL TURBOPUMP GEOMETRIC DESCRIPTION

Length	48.8-in.	124 cm
Diameter (pump discharge)	24.0-in.	61 cm
Weight	585 lb	266 Kg
Inlet/Exhaust Diameters		
a. Pump Inlet	10.0-in.	25.4 cm
b. Pump Discharge	4.8-in.	12.2 cm
c. Turbine Inlet	4.6-in.	11.7 cm
d. Turbine Exhaust (Dual)	5.8-in.	14.7 cm
Rotating Weights and Inertias		
Main Spool		
a. Weight	47.3 lb	21.5 Kg
b. Inertia	1.1778 lb-in.-sec^2	1.3568 Kg-cm-sec^2
Inducer Spool		
a. Weight	48.9 lb	22.2 Kg
b. Inertia	0.8125 lb-in.-sec^2	0.936 Kg-cm-sec^2

TABLE IV

TWIN-SPOOL TURBOPUMP MECHANICAL DESIGN PARAMETERS

PARAMETER	NOMINAL OPERATING POINT	
PUMPING FLUID	LH_2	
DRIVING FLUID	GH_2	
MAIN SHAFT POWER	4610 hp	3438 kw
INDUCER SHAFT POWER	348 hp	260 kw
MAIN SHAFT SPEED	22000 rpm	2303 rad/s
INDUCER SHAFT SPEED	11600 rpm	1215 rad/s
PUMP STATIC DISCHARGE PRESSURE	600 psia	413 N/cm^2
PUMP STATIC SUCTION PRESSURE	20 psia	13.8 N/cm^2
PUMP INLET TOTAL TEMPERATURE	37°R	21°K
TURBINE TOTAL INLET PRESSURE	329 psia	227 N/cm^2
TURBINE STATIC EXHAUST PRESSURE	45 psia	31.0 N/cm^2
TURBINE INLET TOTAL TEMPERATURE	1200°R	667°K

Nominal Speed, N_{HD}, is the aerodynamic/hydraulic design speed.

Mechanical Design Speed, N_{MD}, is taken as 1.15 times nominal speed. The turbopump is to withstand a minimum of five excursions of 30 sec each, at this speed, without detrimental yielding, burst or rupture, severe rubs, or blade failures.

Burst Speed is established as a minimum of 1.2 times the mechanical design speed.

Yield Factor of Safety on Pressure or Inertia Load is limited to a minimum value of 1.18.

Ultimate Factor of Safety on Pressure or Inertia Load is limited to a minimum value of 1.25.

Cyclic or Vibration Loads are based upon a modified Goodman diagram with a 1.25 factor of safety imposed.

Critical Speeds are to be removed from the expected operation spectrum.

Both the yield and ultimate factors of safety are applicable at the nominal and mechanical design speeds.

For purposes of mechanical design, the power requirement of both the main and inducer stages was assumed to vary as the cube of the speed ratio.

$$\frac{HP_1}{HP_2} = \left(\frac{N_1}{N_2}\right)^3$$

Values of speed and power for both the main and inducer stages at the nominal design point and the mechanical design point are shown on Table V.

D. COMPONENT DESIGN

The Twin-Spool Turbopump was designed utilizing an existing single-spool NERVA Mark III Mod 4 Technology Turbopump (P/N 1115700-9) as the main stage. This single-spool design required modifications to satisfy the coaxial Twin-Spool configuration shown on Figure No. 79. The single-spool NERVA Mark III Mod 4 Technology Turbopump design information is contained in Reference 17.

1. Modified Main-Stage Turbopump Components

a. Pump Housing

The standard configuration pump housing was replaced with a housing having a diffuser vane inlet angle of 8.0-degrees (0.1396 rad) and

TABLE V

MECHANICAL DESIGN SPEED AND POWER REQUIREMENTS

	MAIN-STAGE		INDUCER STAGE	
NOMINAL SPEED	22000 rpm	(2303 rad/s)	11600 rpm	(1215 rad/s)
NOMINAL POWER	4610 hp	(3438 kw)	348 hp	(260 kw)
MECHANICAL DESIGN SPEED (1.15 x NOMINAL SPEED)	25300 rpm	(2649 rad/s)	13340 rpm	(1397 rad/s)
MECHANICAL DESIGN POWER (1.15^3 x NOMINAL POWER)	7011 hp	(5228 kw)	529 hp	(394 kw)

a diffuser inlet width of 0.40-in. (1.016 cm). The diffuser inlet angle and diffuser width are 9.25-degrees (0.16145 rad) and 0.55-in. (1.40 cm), respectfully, for the standard configuration pump housing.

b. Impeller

Modification to the main turbopump included reducing the impeller discharge diameter from 12.25-in. (31.1 cm) to 10.4-in. (26.4 cm).

An additional modification to the basic main-stage impeller design was to enlarge the bore diameter to allow for the coaxial low-speed inducer shaft. The impeller hub tangential stress was calculated at the bore and found to be 23,000 psi (15,850 N/cm^2). This results in a positive margin of safety of 2.0 for the aluminum impeller (7075-T73) at the mechanical design speed (see Figure No. 83).

c. Turbine Rotors

The solid turbine rotors were modified to a configuration having a 1.2-in. (3.05 cm) diameter hole at the center to accommodate the inducer stage shaft. The calculated burst speed was placed at a minimum value of 35,600 rpm (3720 rad/s) for the rotor assembly.

The natural frequency of the first-stage rotor was determined by analysis and test. The resonant speed was determined to be 25,900 rpm (2710 rad/s) for the second nodal diameter mode.

d. Main-Stage Shaft/Coupler

The main-stage shaft design was altered to make provisions for the coaxial low-speed inducer shaft. The impeller is driven by a redesigned coupler which is attached to the shaft. The shaft-to-coupler driving torque is transferred through a spline on the coupler inside diameter. Stress analysis of the external shaft spline reveals a minimum positive margin of safety of 0.47 at the nominal design speed conditions, considering one-fourth of the spline teeth in contact (see Figure No. 84).

e. Exhaust Manifold

The exhaust manifold, as used on the positive NPSP turbopumps, was modified to an annular design for use on the Twin-Spool Turbopump. Modification was necessary to provide a turbine-end bearing support for the low-speed shaft. The change consisted of welding a cylindrical inner shell to the flat end of the housing to provide access to the turbine-end bearing support housing of the low-speed shaft (see Figure No. 85).

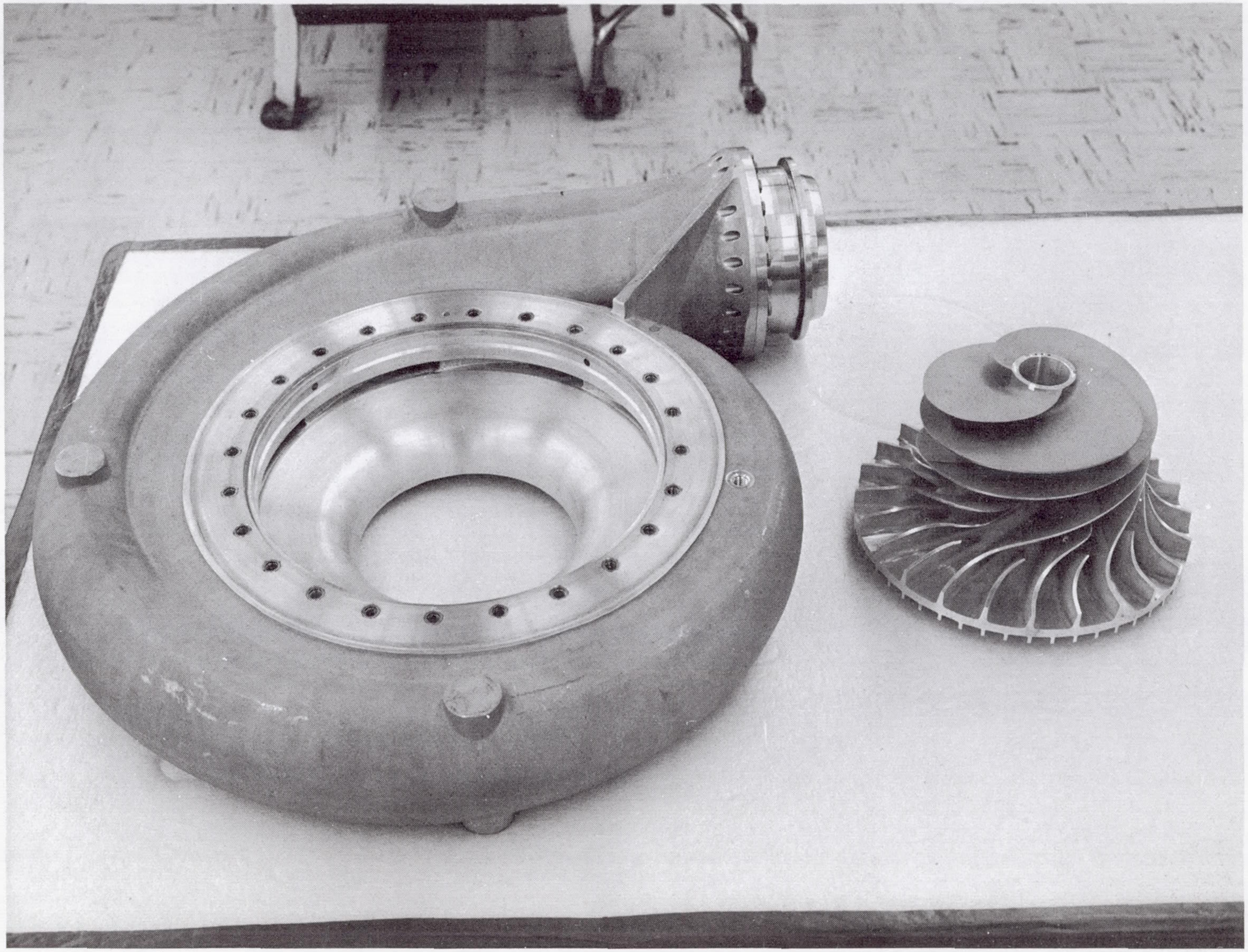


Figure 83. - Pump Housing and Main Impeller.

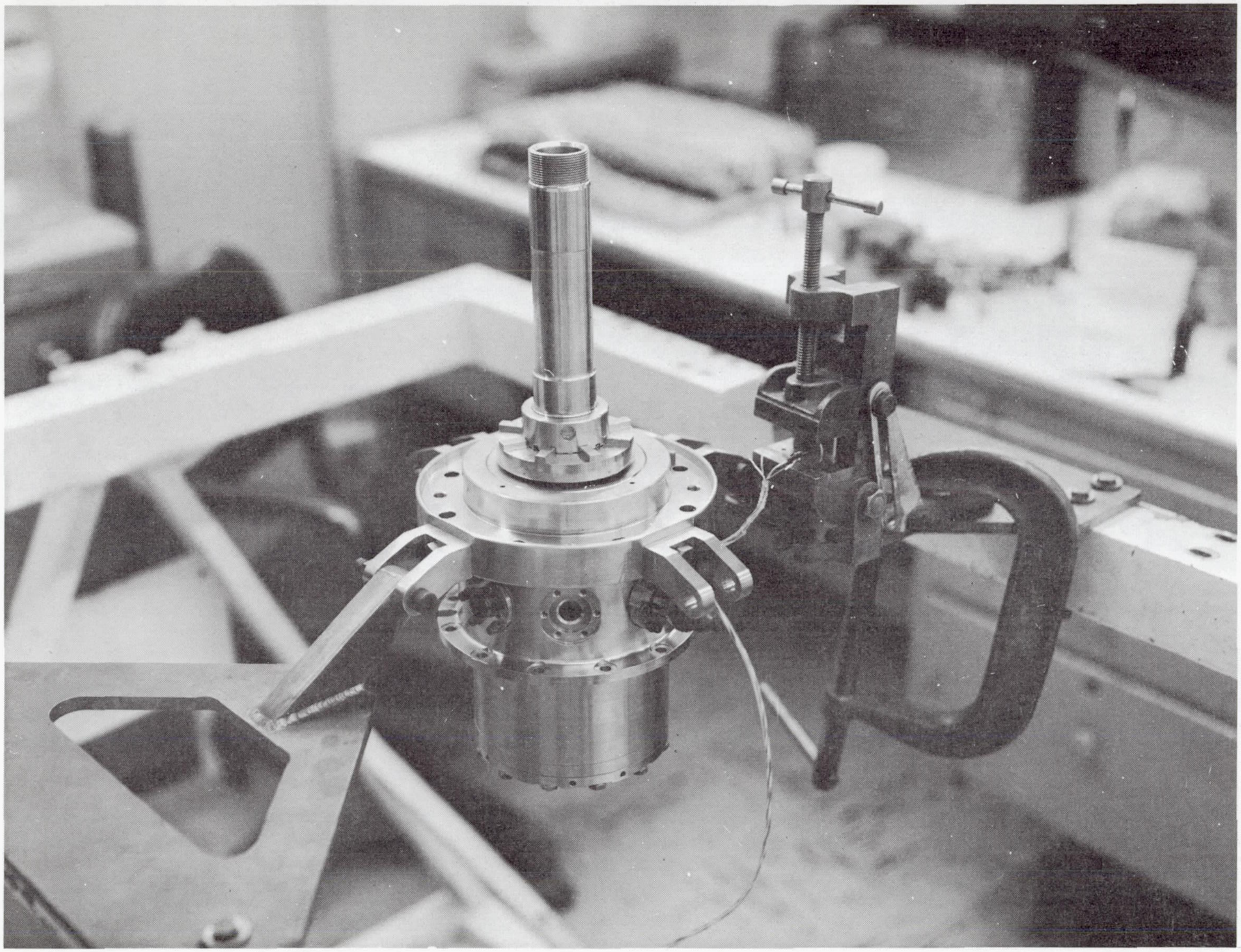


Figure 84. - Shaft/Coupler - Bearing Housing Assembly.

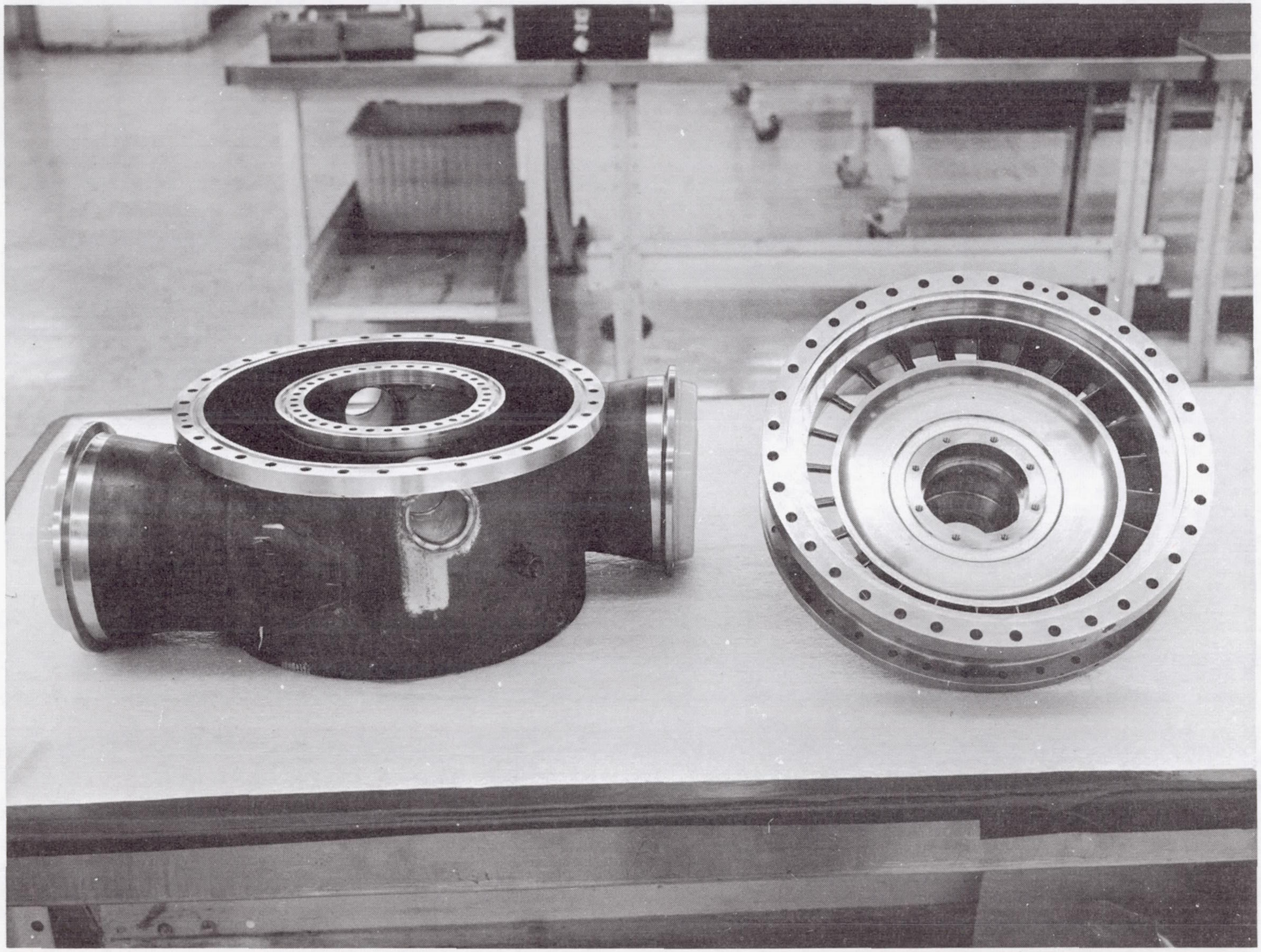


Figure 85. - Exhaust Collector/Exhaust Stator.

2. New Components for Zero NPSP Twin-Spool Turbopump

a. Inducer

The inducer is an eight bladed (at the discharge), 10-in. (25.40 cm) tip diameter configuration fabricated from a titanium alloy (A110-AT) forging.

Maximum tangential stress in the inducer hub is 22,600 psi (15,570 N/cm^2), resulting in a margin of safety of +5.0 at the mechanical design speed. Blade root stress levels are higher with a margin of safety of +0.10 at the mechanical design speed.

Inducer vane first natural frequency is calculated to be in the range of 2215 cps to 3215 cps (2215 Hz to 3215 Hz). The lowest value of 2215 cps (2215 Hz) corresponds to a shaft speed of 16,500 rpm (1728 rad/s), which is well above the inducer stage mechanical design speed. No major forcing frequencies lie in the first critical speed range.

The inducer along with the main stage impeller is shown on Figure No. 86.

b. Inducer Housing

The housing is a weldment design fabricated from CRES 347 and incorporates an eleven vane stator set between the inducer exit and the main pump inlet. The stator vanes serve a dual purpose; they assure axial fluid flow to the main pump stage and provide support for the low-speed shaft system bearing housing (see Figure No. 87).

c. Inducer Turbine

The inducer turbine rotor disc is the same contour as the second-stage rotor of the main-stage turbine. A rotor disc stress analysis was not made because it has the same configuration as the main-stage second rotor and the blade inertia loading is much less. Also, the operational speed is approximately half that of the main-stage second stage.

To expedite fabrication and reduce cost, the inducer turbine rotor was fabricated from a weldment consisting of a short piece of bar stock electron-beam welded to a standard turbine rotor forging. The hub is required for support of the turbine-end inducer shaft radial load bearing. Both the rotor forging and bar stock are A286 material.

Analysis of the inducer turbine rotor blades indicates a total stress level of 13,760 psi (9480 N/cm^2) at the mechanical design conditions of 13,340 rpm (1398 rad/s) and 529 hp (394 kw). Blade resonant frequencies were calculated and correspond to the following shaft speeds within the operating range:

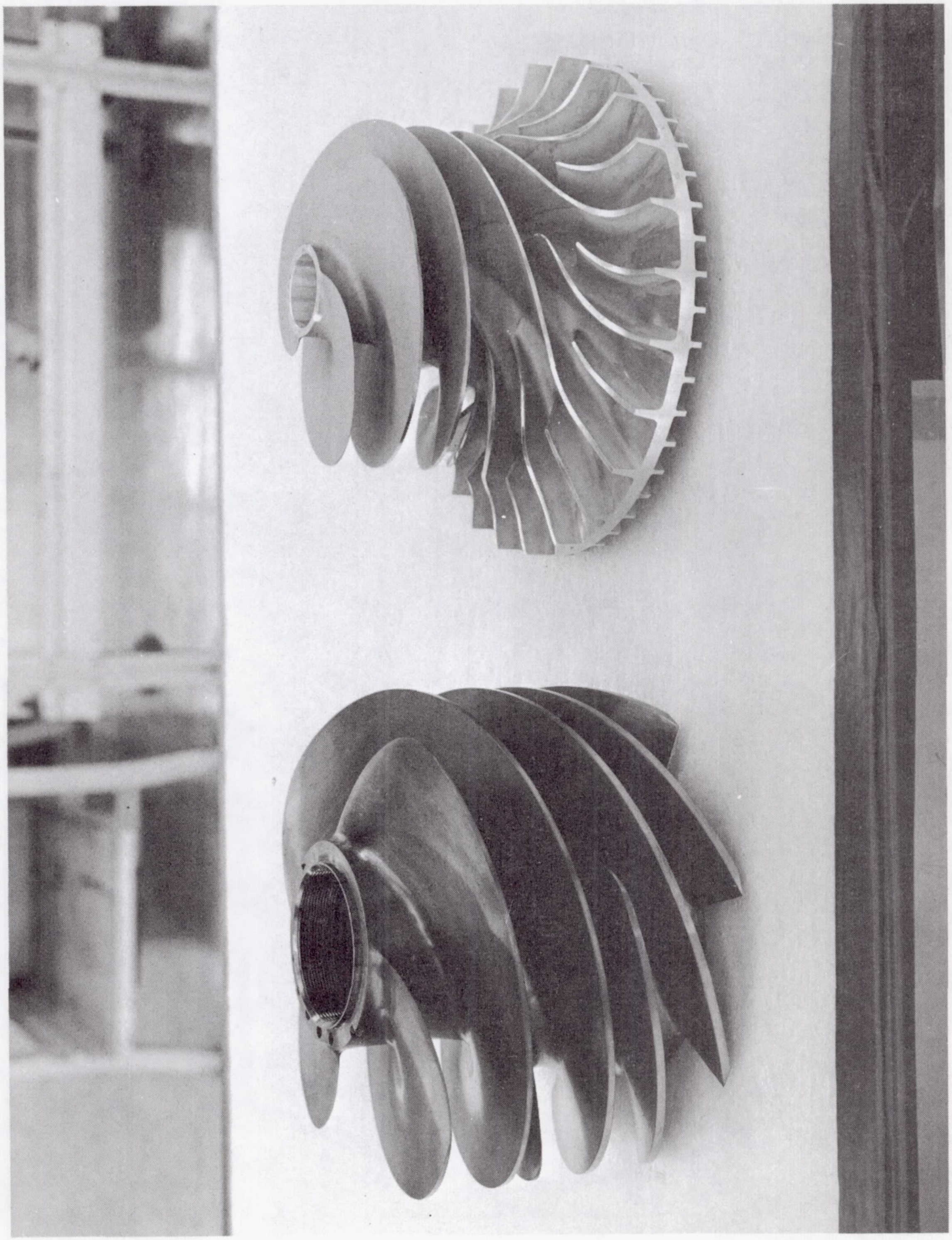


Figure 86. - Inducer and Main-Stage Impeller.

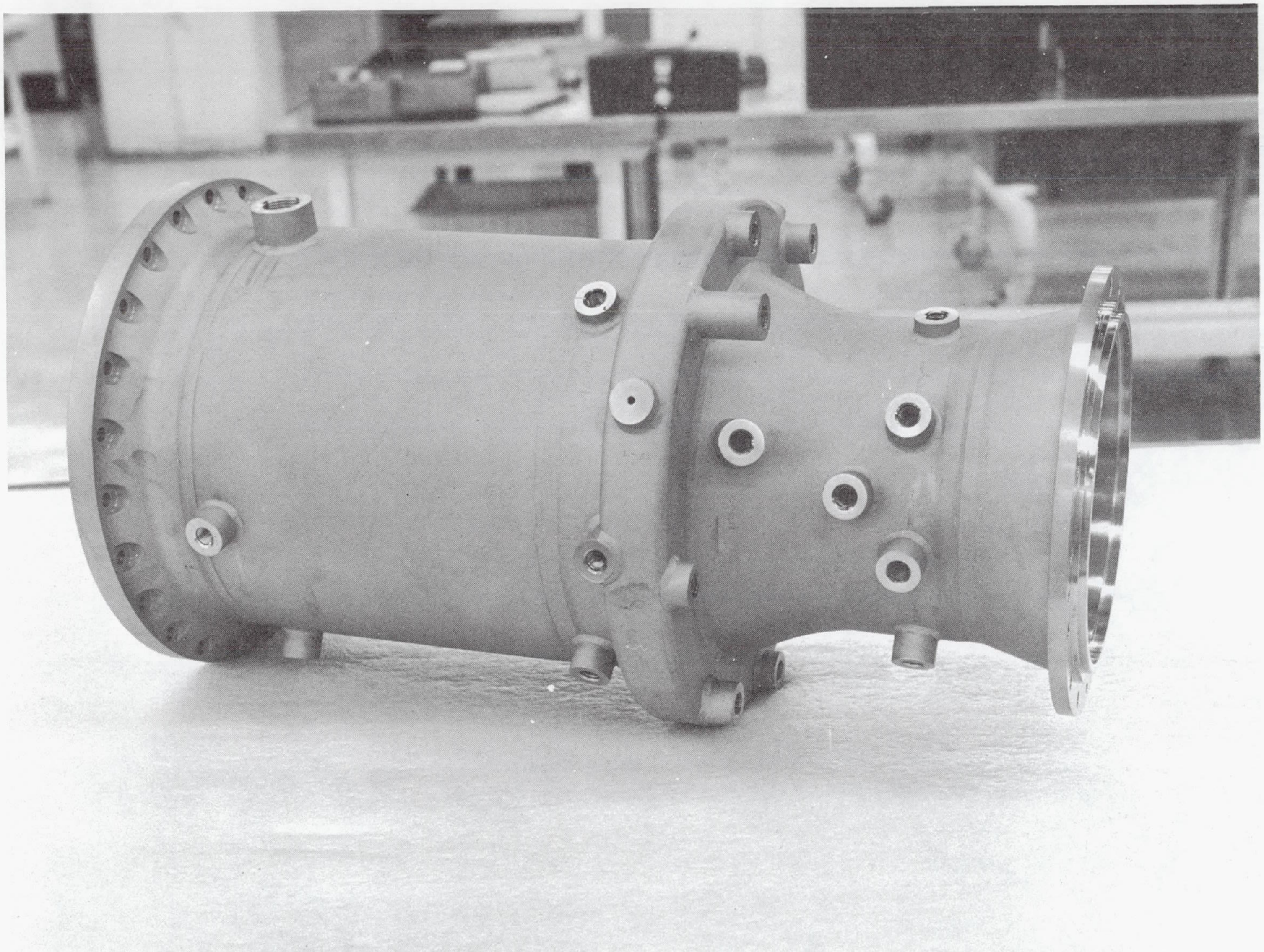


Figure 87. - Inducer Housing.

Shaft Speed rpm	rad/sec	Mode of Vibration
4000	419	First bending - minor axis
5000	524	Torsional
7500	785	First bending - major axis
8600	900	Second bending - minor axis

Prolonged turbopump operation at inducer shaft speeds corresponding to the resonant speeds of the two modes about the minor axis were avoided to reduce the probability of developing fatigue cracks in the relatively flat blades.

Figure No. 88 shows the inducer turbine rotor and the inducer turbine stator.

d. Inducer Shaft

The inducer is connected to the inducer turbine by a 0.980-in. (2.49 cm) diameter solid shaft extending through the hollow shaft system of the main-stage rotating assembly. The shaft is fabricated from Inconel X-750 bar stock.

Torque to the inducer and from the inducer turbine rotor is transferred to the shaft by a spline drive at each end. Spline stress levels are low because of the relatively low power required to drive the inducer. The margin of safety for the inducer rotor spline is +1.12.

The inducer shaft and other major inducer stage rotating components are shown on Figure No. 89.

e. Inducer Shaft Bearings

The low-speed shaft system is supported on the same configuration and size (50 mm) bearings as is the main shaft. A radial load bearing (roller) is located at each end of the shaft. Axial thrust is accommodated through two ball bearings located within the low-speed inducer bearing housing.

Bearing coolant is supplied to the low-speed bearings by means of four, 0.25-in. (0.635 cm) diameter lines extending from the high pressure pump housing volute to a manifold on the inducer housing. The coolant enters the bearing housing through holes in the inducer housing stator vanes and passes through the bearing retaining labyrinth. A five-micron filter was placed in each of the four lines to prevent contaminants from entering the bearing cavity.

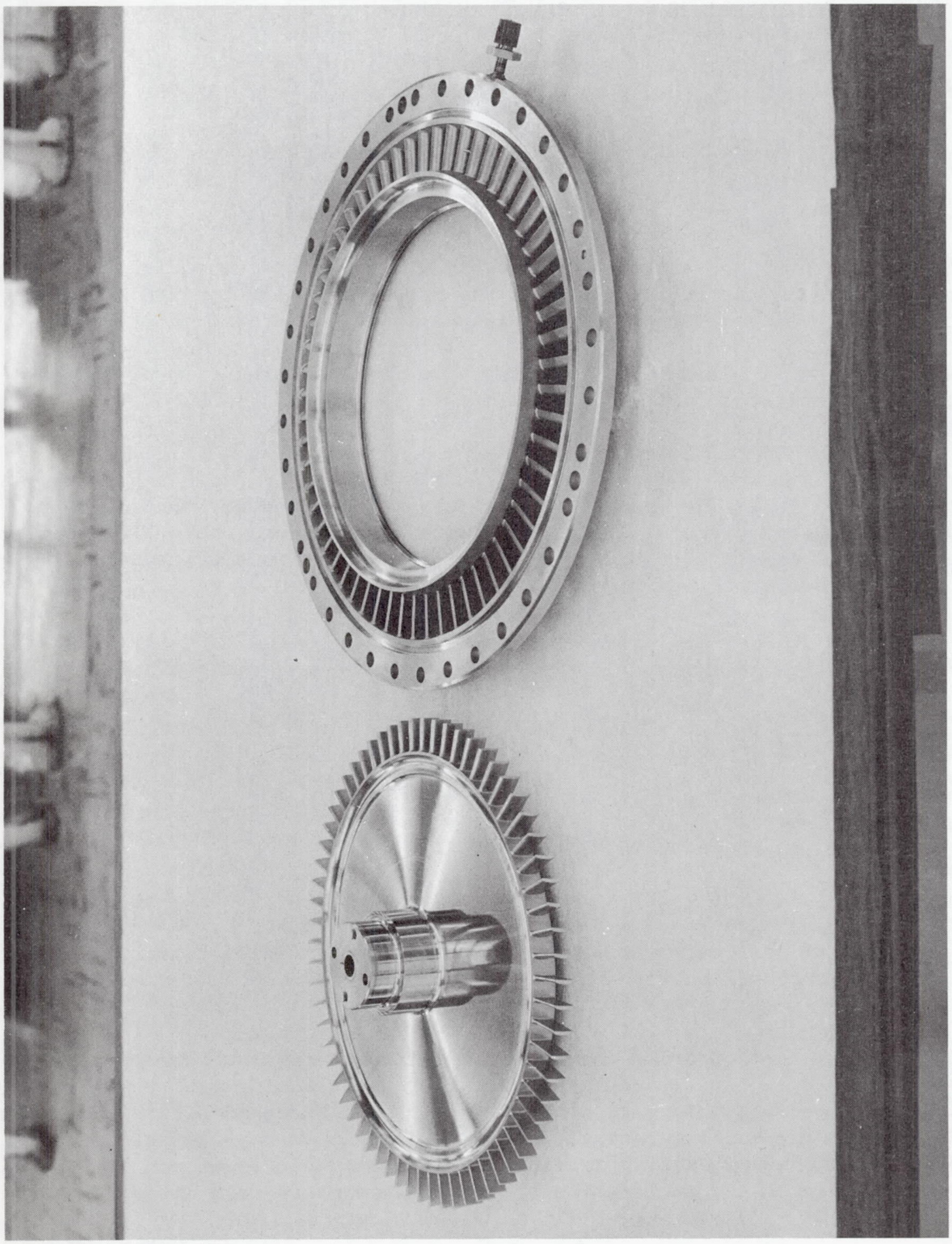


Figure 88. - Inducer Turbine Rotor/Stator

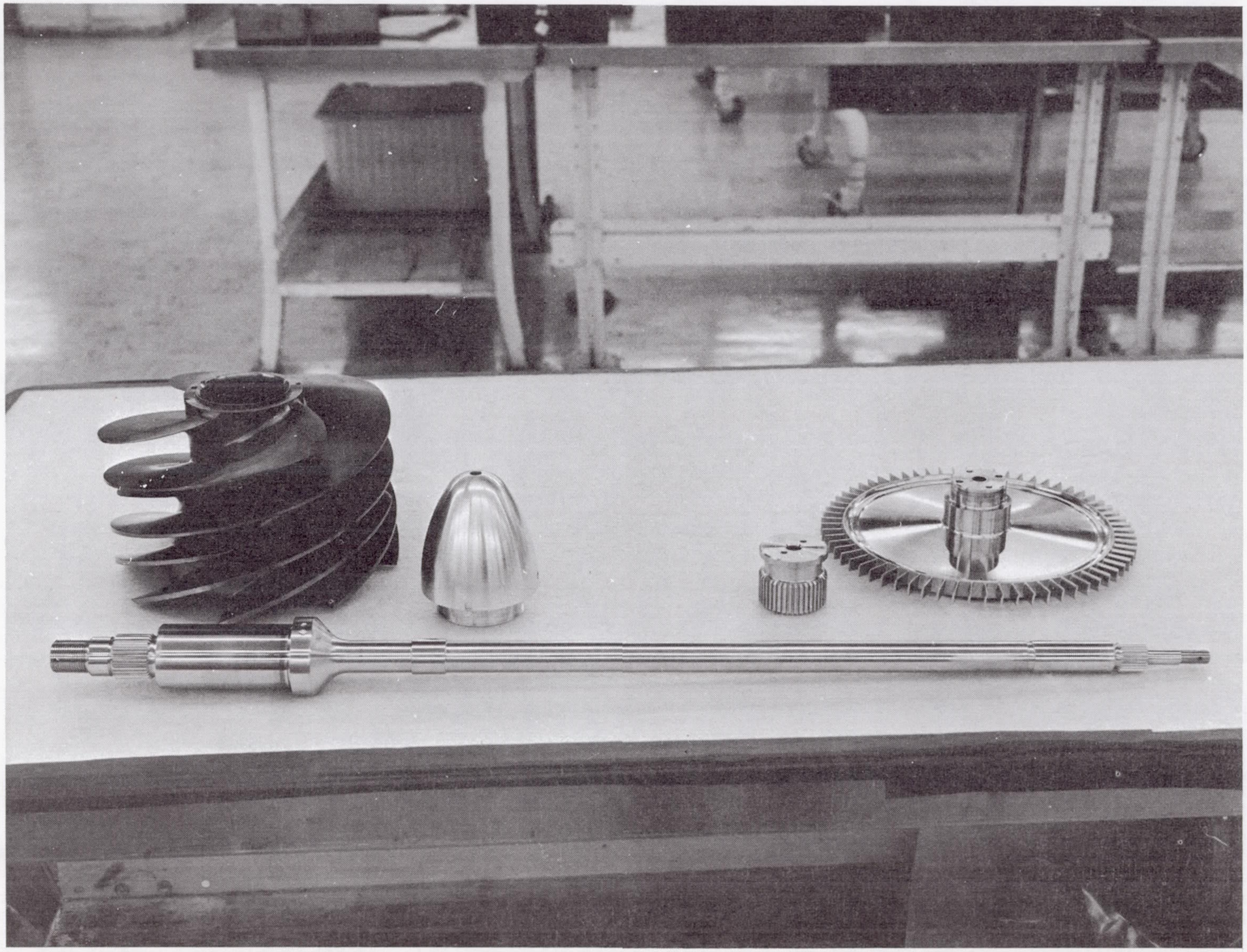


Figure 89. - Inducer/Shaft/Inducer Rotor.

The two bearing retaining labyrinths in the inducer bearing housing were designed so that the bulk of the coolant flows through the three bearings.

The single, radial load bearing on the inducer turbine rotor hub of the low-speed shaft is supplied coolant through a filtered single, 0.250-in. (0.635 cm) diameter tube extending from the pump housing volute to the access plate covering the end of the low-speed shaft.

Figure No. 90 is a plot of predicted bearing coolant flow for both the inducer and turbine end bearings and as a function of the pressure differential across the orifices in the coolant lines. These curves are based upon data obtained from water flow tests.

f. Inducer Turbine Stator

The 59-vane inducer turbine stator is fabricated from CRES 347. The vanes are integrally machined from a forging ring with the outer shroud being brazed to the vanes to provide support. Pins provide a mechanical lock between the blade row and the outer shroud (see Figure No. 91).

g. Exhaust Stator

The exhaust stator is a dual-purpose component in the Twin-Spool Turbopump. The stator vane profile provides for gas turning prior to exiting in the exhaust manifold. The exhaust stator assembly also supports the turbine-end low speed shaft radial load bearing.

Fabrication is similar to that of the inducer stator. The vanes are integrally machined and brazed to the outer shroud. Pins at every other vane provide a mechanical lock. The entire assembly is made from CRES 347 material (see Figures No. 85 and No. 92).

h. Speed Measurement System

Dual proximity probes are used for sensing the inducer shaft speed. These probes are identical to those used for the main-stage. A speed pick-up gear is located aft of the inducer turbine rotor. The difference between the main-stage system and the inducer stage speed pick-up system is that there are less gear teeth in the inducer system because of the smaller gear diameter.

i. Shaft Seals

The flow between the high-speed and low-speed shafts is controlled with labyrinths at the end of the main-stage impeller and at the downstream face of the second rotor. This is done to prevent the turbine drive gas from mixing with the liquid hydrogen in the main pump inlet causing a

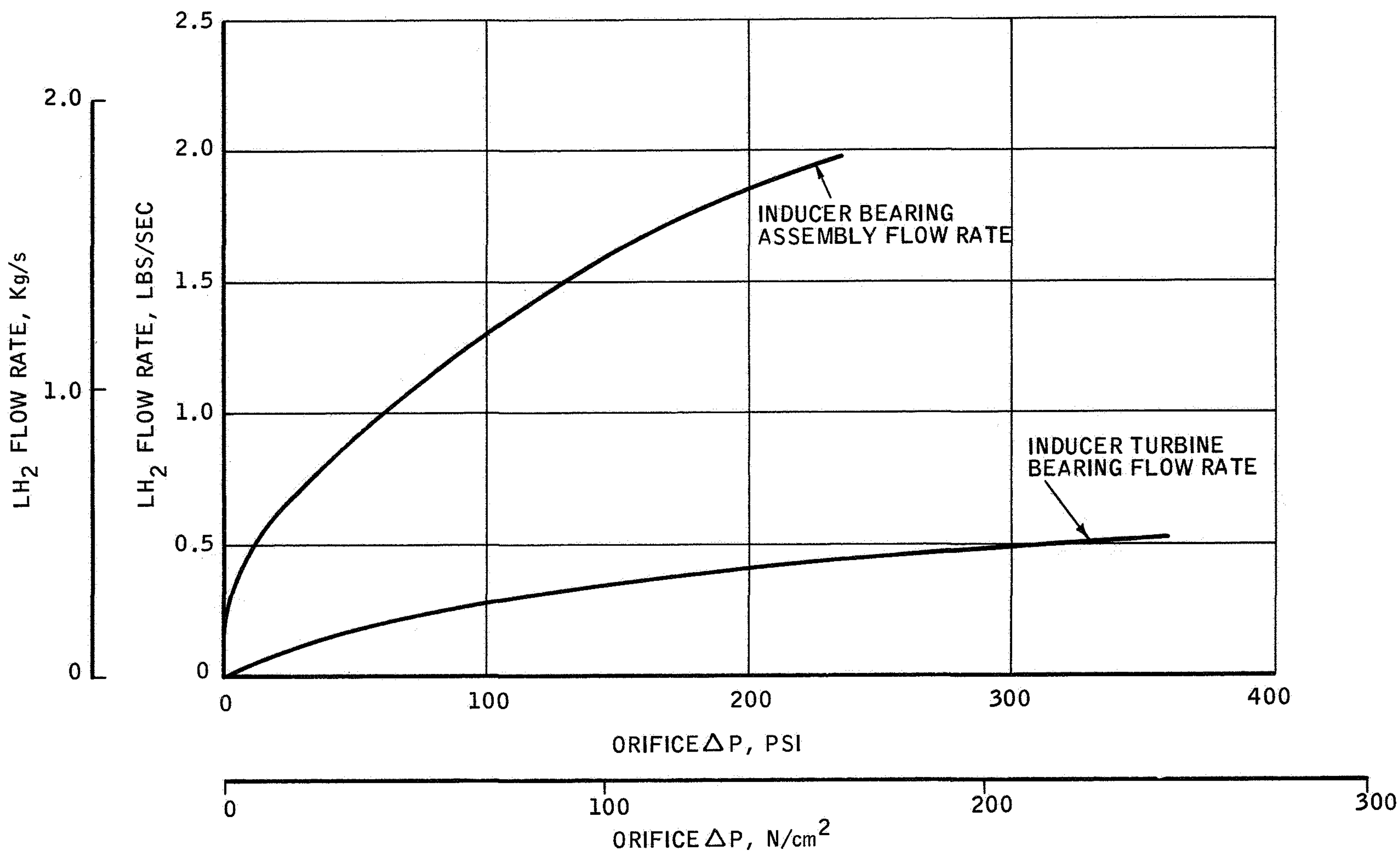


Figure 90. - Predicted Inducer Stage Bearing Coolant Flow Rates - Based Upon Orifice Calibrations in Water.

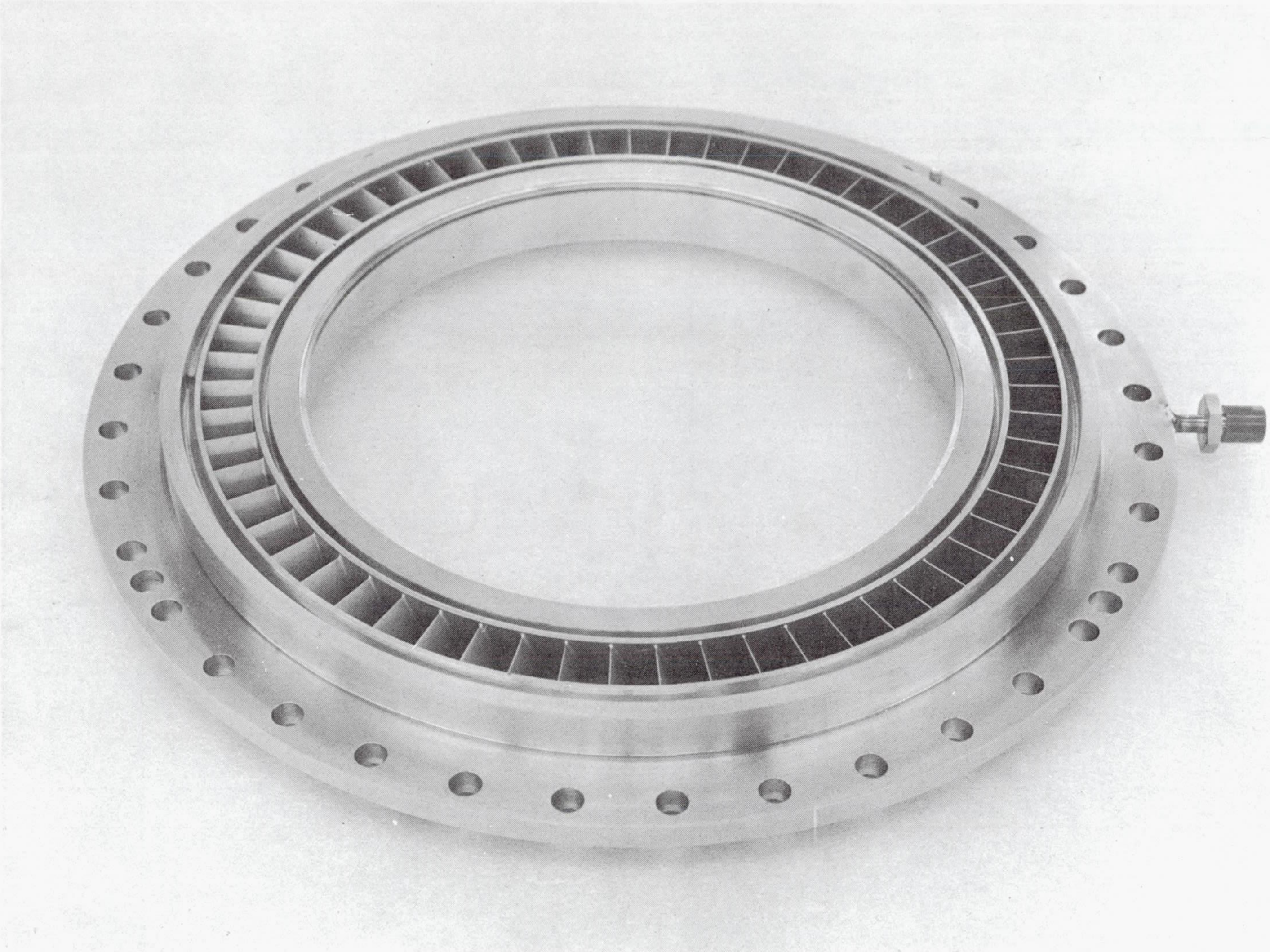


Figure 91. - Inducer Stator.

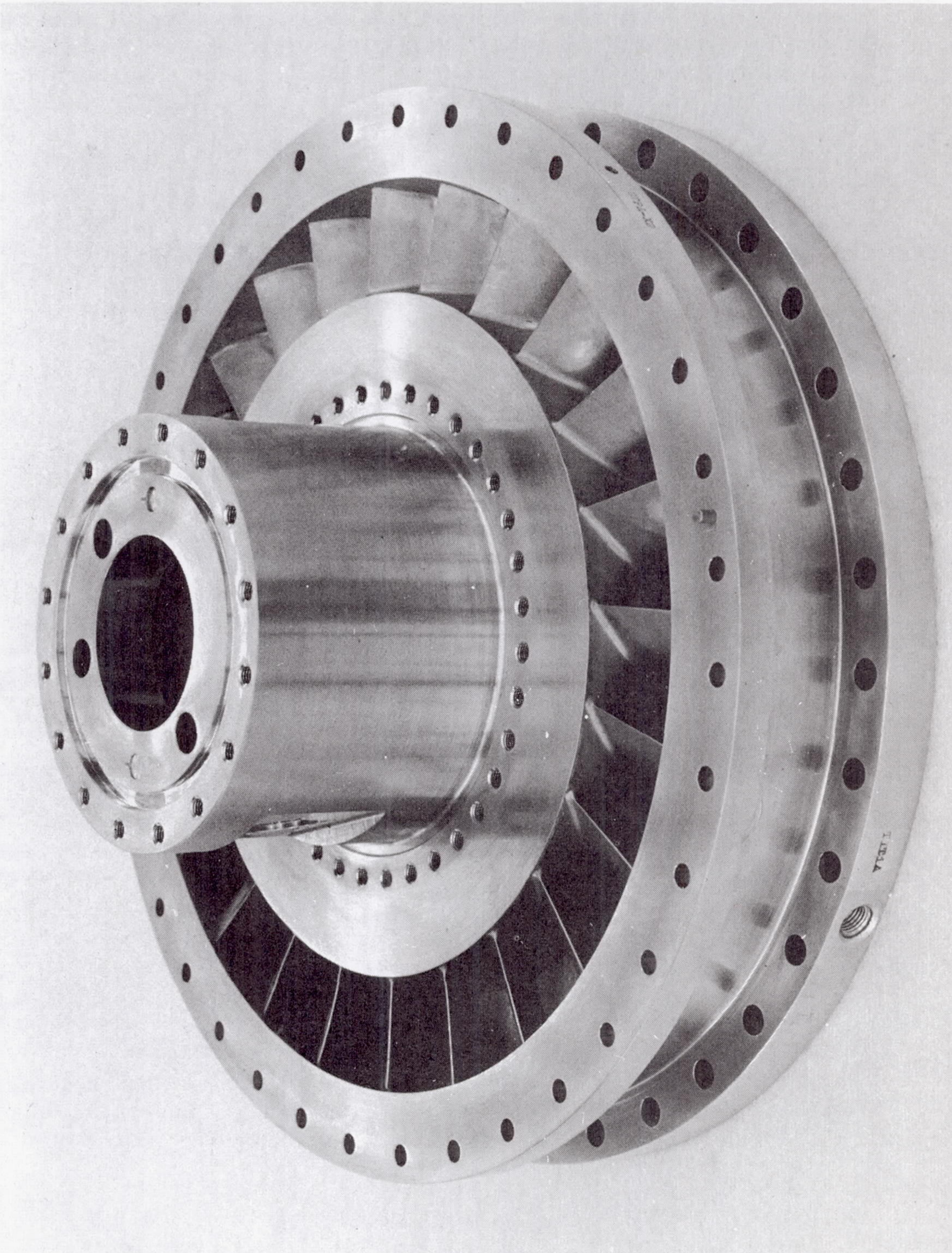


Figure 92. - Exhaust Stator.

degradation in pump performance. The cavity is designed to be pressurized with a portion of the bearing coolant from the main-stage bearing housing. Coolant enters this area through six, 0.087-in. (0.221 cm) diameter holes located in the clutch portion of the main-stage shaft. The two labyrinth seals are replaceable rings made from soft aluminum alloy. A soft alloy was selected to allow for rub (or wiping) between the two shafts at these close-fitting points. Clearances and flow areas are presented in Table VI for all labyrinth seals in the turbopump.

j. Inducer Shaft Critical Speed

The low-speed shaft resonant frequencies were calculated to be:

Mode	Shaft Speed rpm	Shaft Speed rad/s
First	1096	115
Second	6680	700
Third	12040	1261

These values of shaft critical speed are based upon measuring the spring constant of each bearing mount with the turbopump mounted in Test Stand H-6. A series of static loads were applied at each bearing location and the deflections noted. The resulting spring rates (load per unit deflection) for each bearing support are:

Inducer end	K = 31090 lb/in.	(544 N/m)
Inducer turbine end	K = 64670 lb/in.	(1131 N/m)

The first critical speed value of 1096 rpm (115 rad/s) is encountered during start-up and shutdown only. Therefore, it was considered to be of major importance. Even though the second critical speed was found to be within the operational range of the low-speed shaft, no bearing problems were foreseen because it was anticipated that the bearing loads would be moderate.

The inducer stage components materials were selected based upon strength and thermal environment requirements. The major components and their materials are as shown in Table VII.

TABLE VI

LABYRINTH GAP CLEARANCES AND FLOW AREAS
TEMPERATURE = 530°R (294K)

	RADIAL CLEARANCE		FLOW AREA	
	in.	cm	$in.^2$	cm^2
INDUCER-STAGE BEARING RETAINING LABYRINTH - INDUCER SUCTION END	0.0110/0.0114	0.0279/0.0290	0.0882	0.56907
INDUCER-STAGE BEARING RETAINING LABYRINTH - INDUCER DISCHARGE END	0.0036/0.0038	0.0091/0.0097	0.0294	0.18969
INDUCER-STAGE BEARING RETAINING LABYRINTH - INDUCER TURBINE END	0.0044/0.0047	0.0112/0.0119	0.0337	0.21743
MAIN-STAGE BEARING RETAINING LABYRINTH	0.0044/0.0047	0.0112/0.0119	0.0422	0.27227
MAIN SHAFT/INDUCER SHAFT LABYRINTH PUMP SIDE	0.0050/0.0057	0.0127/0.0145	0.01858	0.11988
MAIN SHAFT/INDUCER SHAFT LABYRINTH TURBINE SIDE	0.0040/0.0045	0.0102/0.0114	0.01349	0.08704
MAIN-STAGE TURBINE STATOR LABYRINTH	0.015/0.021	0.0381/0.0533	0.4938	3.18600
INDUCER-STAGE TURBINE STATOR LABYRINTH	0.027/0.033	0.0686/0.0838	0.7938	5.12160

TABLE VII

INDUCER-STAGE COMPONENTS MATERIALS

COMPONENT	MATERIAL
Inducer	Titanium A-110
Inducer Housing	CRES 347
Spinner	Aluminum 6061
Inducer Bearing Housing	CRES 347
Inducer Bearing Retaining Labyrinths	CRES 347
Inducer Shaft	Inconel X750
Inducer Turbine Rotor	A286
Inducer Turbine Ring Seal	A286
Inducer Turbine Nozzle	CRES 347
Inducer Turbine Exhaust Stator	CRES 347
Inducer Speed Pick-Up Sleeve	AM350

E. TURBOPUMP WEIGHT

The Twin-Spool Turbopump was weighed following completion of assembly. Its weight (not including closures) is 585 lb (266 Kg). The weight of the main-stage turbopump was 385 lb (175 Kg), before modification to the Twin-Spool configuration, indicating that the conversion added 200 lb (91 Kg) of weight. It should be noted that both the main-stage turbopump and the components associated with the zero NPSP configuration were not designed with minimum weight as a criterion.

With minimum weight as a criterion for a flight engine, it is estimated that a redesign of the main-stage turbopump (maintaining performance and flow characteristics) would result in an assembly weight of approximately 310 lb (141 Kg). An optimized flightweight Twin-Spool (zero NPSP capability) turbopump would be approximately 55% heavier than the flightweight Single-Spool. Specifically, the Twin-Spool Turbopump would be expected to weight approximately 480 lb (218 Kg).

F. POST-TEST DISASSEMBLY

The Twin-Spool Turbopump was disassembled after completion of the test program. The condition of all components was fairly good and as anticipated for the test conditions and accumulated run time.

The total operational time (including seven start-ups and shutdowns), of the Twin-Spool Turbopump exceeded 60 min (3600 sec) duration. Approximately 45 min (2700 sec) of the total duration were accumulated at turbopump operation in the full-speed range.

Evidence of rubbing between the two coaxial shafts and on the two, soft aluminum labyrinths that restrict flow between the shafts is attributed to unbalance, loss of fit, and possible shaft critical speed. An indication of fretting at the contact surfaces of the inducer to bearing spacer and inducer turbine to low-speed shaft also was found. These conditions would be corrected in subsequent Twin-Spool Turbopumps by improving the fits and pilots, improving the balancing, and providing a mid-shaft deflection snubber.

VI. TWIN-SPOOL TURBOPUMP TEST PROGRAM

A. TEST PROGRAM OBJECTIVES AND ACHIEVEMENT CRITERIA

1. Objectives

The six, specific major objectives of the test program were as follows:

a. Development of a digital computer program to predict the steady-state and transient performance (cavitating as well as non-cavitating) of a Twin-Spool Turbopump.

b. Determination of the Twin-Spool Turbopump operational characteristics and experimental verification of the computer prediction method. Appropriate refinement of the mathematical computerized model was to be made based upon the experimental results.

c. Establishment of a basis for selecting a turbopump configuration (single-spool or twin-spool) for future application by establishing performance curves and suction capability.

d. Providing comparison data for this inducer drive system that are usable in relationship to the full-flow and partial-flow hydraulic drives.

e. Providing engine system integration design data in the form of transient and steady-state performance.

f. Providing an alternative base configuration for the hydrogen pumping evaluation of other boost pump configurations (i.e., hubless converging, full-flow, and partial flow inducer concepts).

2. Achievement Criteria

All of the above indicated program objectives were successfully achieved. This achievement was judged upon the basis of an evaluation and comparison of test results in context with the following criteria:

a. Operating characteristics (head rise-capacity) at both design and off-design conditions with zero NPSP and positive NPSP.

b. Transient response in terms of providing main pump NPSP at both chemical and nuclear engine starting rates.

c. Operational sensitivity and stability when subjected to engine-induced conditions (i.e., pump flow rate and turbine pressure ratio variations).

d. Validity of steady-state and transient performance matching analyses and predictions.

e. Mechanical integrity of a prototype twin-spool system.

f. Refined criteria for subsequent final designs.

B. TEST FACILITIES

Aerojet-General Sacramento Facility Test Stand H-6 was utilized to conduct the testing program. Originally designed for turbopump development testing, it offered the most economical approach for accomplishing program objectives. Only minor modifications to the existing special test equipment, turbopump assembly handling fixtures, work platforms, and the turbine exhaust duct were needed to accommodate the hardware configuration.

Test Stand H-6 is part of the Test Zone H NERVA test complex shown on Figure No. 93. The basic stand structure houses three separate test positions with the propellant run vessels positioned overhead. The spherical vessels within the superstructure are high-pressure Dewars, while the large cylindrical vessel located atop the superstructure is a low-pressure Dewar. It was used to supply the pumping fluid to the test article.

A liquid hydrogen catch vessel and flare stack are located adjacent to the test complex.

High-pressure gaseous hydrogen and nitrogen are supplied from the gas cascade shown on Figure No. 94. The gaseous hydrogen is stored in six, 1300 cu ft vessels at 3500 psig, while the gaseous nitrogen is stored in three, 1300 cu ft vessels at 5000 psig. Additionally, there are liquid hydrogen and liquid nitrogen storage vessels supporting the test complex. Figure No. 95 is a schematic of the supporting equipment and facilities for Test Stand H-6.

Liquid hydrogen is supplied to the pump inlet through an 8-in. vacuum-jacketed line from the 105,000 gal cylindrical overhead run vessel (VH-11). The pump effluent is carried to the 100,000 gal liquid hydrogen catch vessel (VH-10) through a vacuum-jacketed line where approximately 45% to 50% of the liquid hydrogen is recovered.

Gaseous hydrogen from the high-pressure cascade is used as the pressurant in the liquid hydrogen run vessel as well as the fluid for driving the turbine. This gas is filtered and its pressure regulated in accordance with individual test requirements. Regulating the pressurant gas flow in the liquid hydrogen vessel provides control of the pump inlet conditions. Two, servo-controlled, hydraulically-operated flow control valves are utilized to maintain a steady liquid hydrogen vessel ullage pressure. One of these fast-response valves regulates the flow of pressurant gas, while the other regulates the vessel vent system. Another flow control valve is located in the pump discharge line to permit regulation of the flow rate over the operating range.

Figure 93. - Test Zone H.

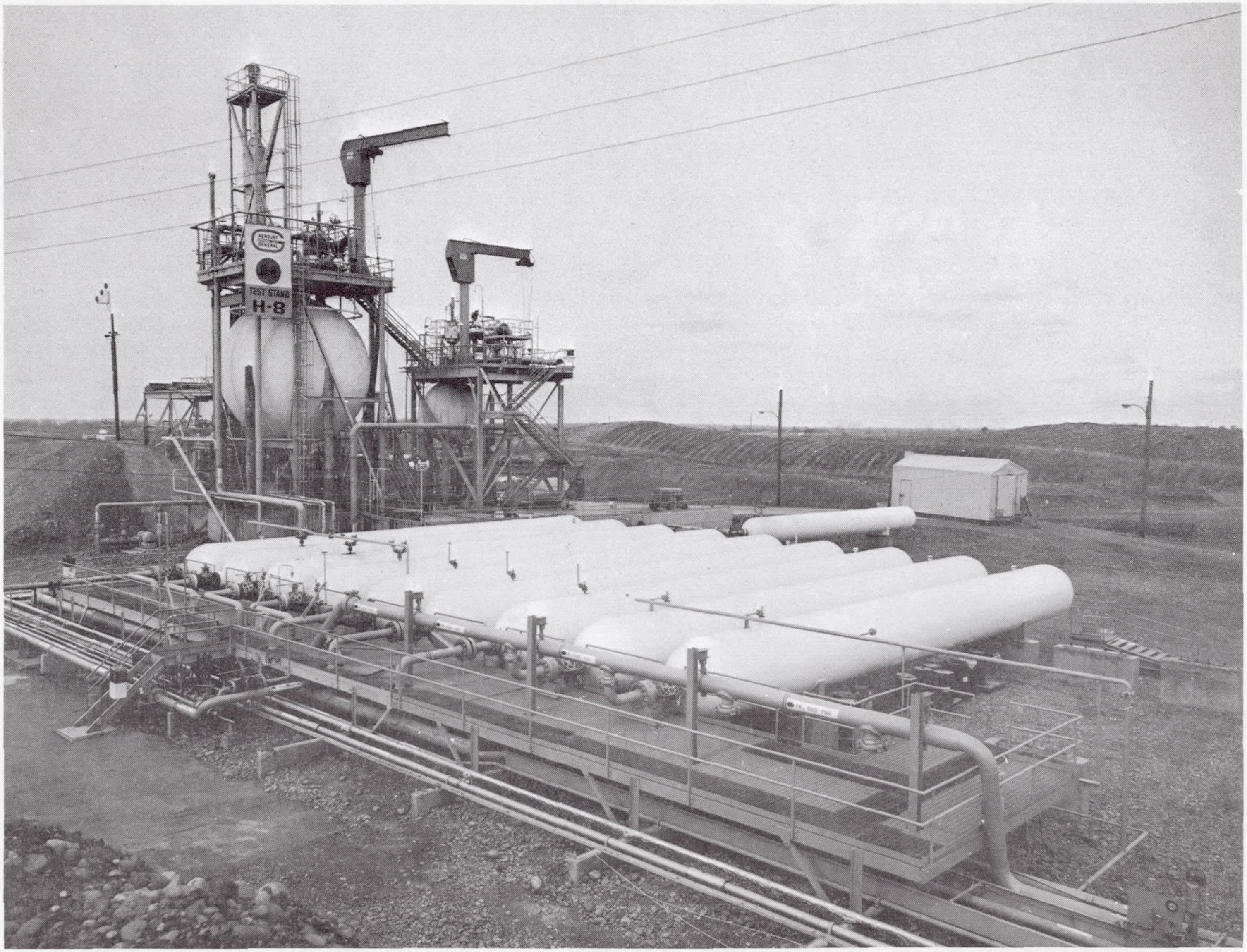


Figure 94. - High-Pressure Cascade.

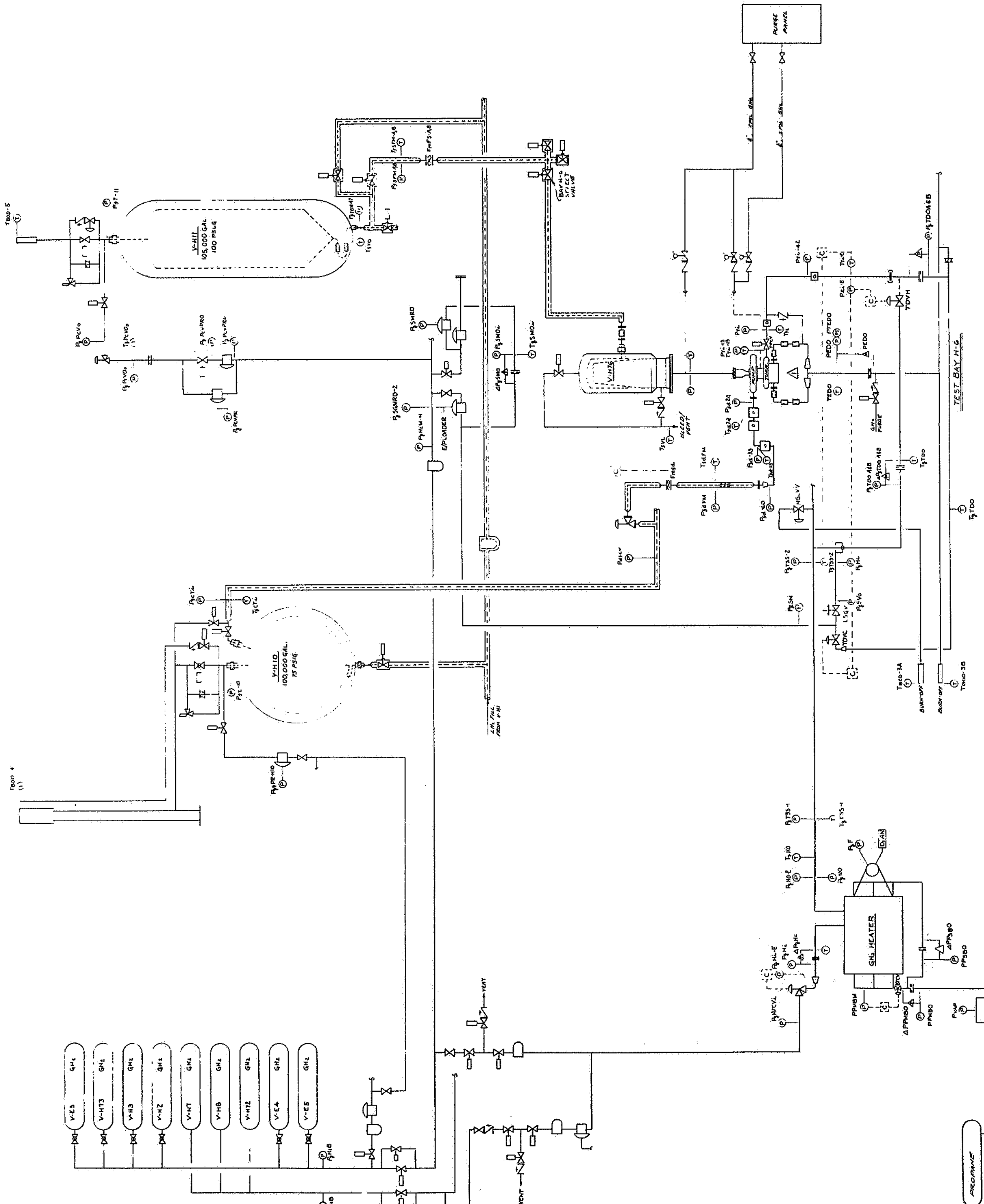


Figure 95. - Test Stand H-6 Schematic.

The gaseous hydrogen used as the turbine drive gas is supplied from the high-pressure cascade at ambient temperature. Its pressure is regulated to satisfy the requirements of the test article by means of a turbine drive valve located upstream from the turbine inlet (see Figure No. 95).

The turbine exhaust line has provisions for an orifice, which is used to vary the turbine back-pressure.

C. CONTROLS SYSTEM

The control system used during the Twin-Spool Turbopump test series is shown on Figure No. 96. During the turbopump operation, control systems were used to calculate as well as to display Q/N and NPSP. They also provided control of the main-stage shaft speed and pump flow rate. Pump flow rate was based upon either volumetric flow rate or flow parameter (Q/N) to meet the operational requirements of the test program.

The control system monitored both shaft speeds and provided an automatic shutdown if a loss of speed signal or an overspeed occurred. It also provided an automatic shutdown upon the loss of hydraulic pressure or over-pressure of the liquid hydrogen vessel, turbine inlet line, or pump discharge line.

D. INSTRUMENTATION

During the test series, 146 channels of data were acquired, including pressure, temperature, flow rate, NPSP, turbine parameters, high frequency data, vibration, and the key parameters of inducer and main pump shaft speed. A summary of the data measured and the recording methods is provided on Tables VIII and IX.

All of the parameters needed to complete a performance evaluation were measured. Temperatures as well as pressure upstream and downstream from the inducer, the main-stage pump, the main-stage turbine, and the inducer turbine, as well as the speed of both spools were measured. High-frequency pressure meaurements were made in front of the inducer inlet, at the inducer exit, and stator inlet, and the stator outlet to allow evaluation of the inducer performance

All the critical measurements were made redundantly to assure that the essential data were acquired during a test. A complete listing of the parameters measured as well as the recording method used for each is shown on Table X. The location and description of the parameters measured are shown on Figure No. 97. Views of the turbopump installed in the test stand are included as Figures No. 98 through No. 103.

Continuous data sampling was taken during the operation of the turbopump. Both the strip chart and the analog-to-digital records were taken.

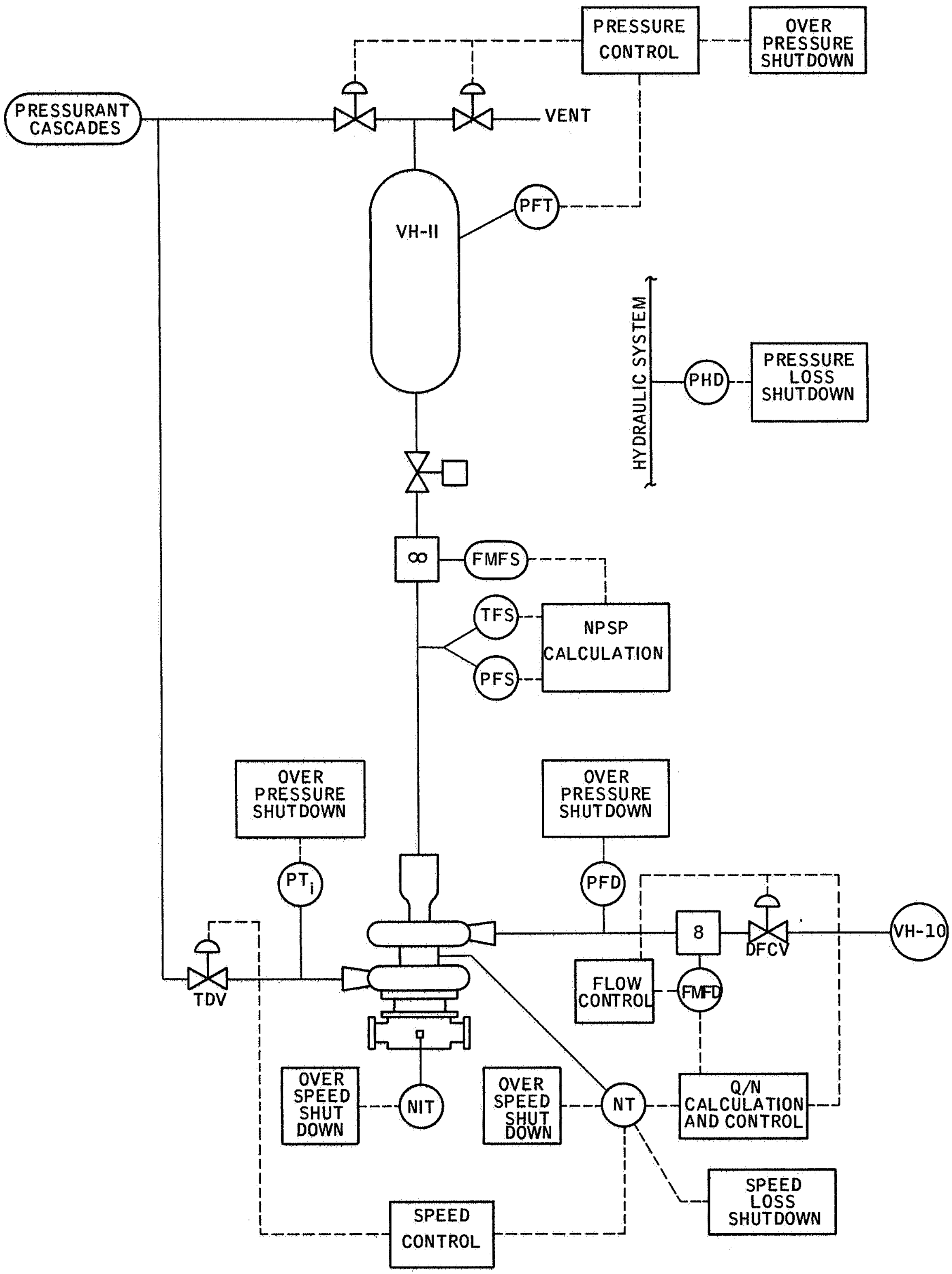


Figure 96. - Control System.

TABLE VIII

SUMMARY OF DATA MEASURED

DATA	NUMBER OF CHANNELS		
	TPA	FACILITY	TOTAL
PRESSURE	56	17	73
TEMPERATURE			
RTT	13	2	15
CR/AL THERMOCOUPLE	19	2	21
HIGH FREQUENCY			
ACCELEROMETERS	5	0	5
PHOTOCON (PRESS)	4	0	4
KISTLER (PRESS)	3	0	3
E.O.S. (PRESS)	1	0	1
FLOW RATE	3	1	4
SPEED	4	0	4
VALVE TRACE	0	5	5
SWITCH TRACE	0	9	9
AXIAL THRUST	2	0	2
SIGNALS FROM CONTROL SYSTEMS	2	2	4

TOTAL DATA = 146 CHANNELS (+4 FROM CONTROLS SYSTEM)

TABLE IX

SUMMARY OF RECORDING METHODS

RECORDING EQUIPMENT	NUMBER OF CHANNELS		
	TPA	FACILITY	TOTAL
ANALOG TO DIGITAL (BECKMAN)			
40 SAMPLES PER SECOND	39	0	39
20 SAMPLES PER SECOND	30	20	50
10 SAMPLES PER SECOND	20	10	40
OSCILLOGRAPH	14	12	26
STRIP CHART			
BROWN 153X	12	0	12
WESTRONIC D-11A/Y	12	0	12
MOSELEY 680	14	4	18
SANBORN 1584	0	5	5
GENERAL ELECTRIC	1	0	1
X-Y PLOTTER (ELECTRO INSTRUMENTS)	2	0	2
H.F. TAPE (SANGAMO 451 BR)	13	2	15
VISUAL GAUGES (METRONIX)	1	13	14

TOTAL CHANNELS RECORDED = 220 (+14 VISUAL GAUGES)

TABLE X

TURBOPUMP INSTRUMENTATION

Pump Instrumentation

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
PFT	0-100 psig	0-69 $\frac{N}{cm^2}$	20		W			
TFT	0-60°R	0-33°K	40		B			4 in. (10.2 cm) RTT
FMFS	0-10000 gpm	0-6025 $\frac{dm^3}{s}$	40	X	W			
PFMFS	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
TFMFS	0-60°R	0-33°K	20					4 in. (10.2 cm) RTT
PFS53-A	0-100 psig	0-69 $\frac{N}{cm^2}$	40		B			
PFS53-B	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
TFS53-A	0-60°R	0-33°K	20		B			4 in. (10.2 cm) RTT
TFS53-B	0-60°R	0-33°K	20					4 in. (10.2 cm) RTT
PFS26-A	0-100 psig	0-69 $\frac{N}{cm^2}$	40		B			
PFS26-B	0-100 psig	0-69 $\frac{N}{cm^2}$	40	X				
PFS26-C	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Photocon High Frequency Transducer
PFS26-D	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Photocon High Frequency Transducer
TFS26-A	0-60°R	0-33°K	20		B			4 in. (10.2 cm) RTT
TFS26-B	0-60°R	0-33°K	20					4 in. (10.2 cm) RTT
PFS3-A	0-100 psig	0-69 $\frac{N}{cm^2}$	20					
PFS3-B	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Photocon High Frequency Transducer
PFS3-C	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Photocon High Frequency Transducer
PFIo-A	0-200 psig	0-138 $\frac{N}{cm^2}$	40					
PFIo-B	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Kistler High Frequency Transducer
PFIo-C	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		E.O.S. High Frequency Transducer
TFIo	0-60°R	0-33°K	20					1.86 in. (4.7 cm) RTT
PTFIo-A	0-200 psig	0-138 $\frac{N}{cm^2}$	40					Total Pressure

TABLE X (cont.)

Pump Instrumentation (cont.)

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
PTFIo-B	0-200 psig	0-138 $\frac{N}{cm^2}$	40					Total Pressure
PFISo1-A	0-200 psig	0-138 $\frac{N}{cm^2}$	40					Total Pressure
PFISo1-B	0-200 psig	0-138 $\frac{N}{cm^2}$	40					
PFISo1-C	0-200 psig	0-138 $\frac{N}{cm^2}$	20					Hub Static Pressure
PFISo1-D	0-200 psig	0-138 $\frac{N}{cm^2}$	20					Hub Static Pressure
PTFISo1	0-200 psig	0-138 $\frac{N}{cm^2}$	40	X				Total Pressure
PFISo2-A	0-200 psig	0-138 $\frac{N}{cm^2}$	20					
PFISo2-B	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Kistler High Frequency Transducer
TFISo2-A	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
TFISo2-B	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
ΔPFIS	Δ100 psi	Δ69 $\frac{N}{cm^2}$	10		W			Δ(PTFISo1 - PFS26-A)
PFD2-A	0-1000 psig	0-689 $\frac{N}{cm^2}$	40		B			
PFD2-B	0-1000 psig	0-689 $\frac{N}{cm^2}$	40	X				
PFD2-C	0-50 psi P-P	0-34 $\frac{N}{cm^2}$ P-P				X		Kistler High Frequency Transducer
TFD2-A	0-60°R	0-33°K	20		W			2.5 in. (6.4 cm) RTT
TFD2-B	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
ΔPFMS	Δ1000 psi	Δ689 $\frac{N}{cm^2}$	10		W			Δ(PFD2-A - PTFISo1) Y-Axis on X-Y Plotter
FMFD-A	0-10000 gpm	0-6025 $\frac{dm^3}{s}$	40		B			X-Axis on X-Y Plotter
FMFD-B	0-10000 gpm	0-6025 $\frac{dm^3}{s}$	40	X	W			
PFMFD-A	0-1000 psi	0-689 $\frac{N}{cm^2}$	40					
PFMFD-B	0-1000 psi	0-689 $\frac{N}{cm^2}$	40					
TFMFD-A	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
TFMFD-B	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
NPSP	0-50 psi	0-34 $\frac{N}{cm^2}$	40				X	Calculated using PFS26-A and TFS26-A
Q/N	0-1 $\frac{gal}{rev}$	0-0.6 $\frac{dm^3}{rad}$	40		B			Calculated using FMFD-A and NT-A

TABLE X (cont.)

Turbine Instrumentation

Parameter	Range	(SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
PGTDOi-A	0-1000 psig	0-689 $\frac{N}{cm^2}$	40					
PGTDOi-B	0-1000 psig	0-689 $\frac{N}{cm^2}$	10					
TGTDOi-A	220-710°R	122-394°K	20					2.5 in. (6.4 cm) CR/AL Thermocouple
ΔPGTDO-A	Δ100 psi	Δ69 $\frac{N}{cm^2}$	40					
ΔPGTDO-B	Δ100 psi	Δ69 $\frac{N}{cm^2}$	40					
PTi3	0-500 psig	0-345 $\frac{N}{cm^2}$	10					
TTi3	220-710°R	122-394°K	20		W			3.25 in. (8.3 cm) CR/AL Thermocouple
PTTi3-A	0-500 psig	0-345 $\frac{N}{cm^2}$	40		B			Total Pressure
PTTi3-B	0-500 psig	0-345 $\frac{N}{cm^2}$	40	X				Total Pressure
TTi4	220-710°R	122-394°K	10					2 in. (5.1 cm) CR/AL Thermocouple
PITi-A	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
PITi-B	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
TITi-A	220-710°R	122-394°K	10		M			2.5 in. (6.4 cm) CR/AL Thermocouple
TITi-B	220-710°R	122-394°K	10					2.5 in. (6.4 cm) CR/AL Thermocouple
PTITi	0-100 psig	0-69 $\frac{N}{cm^2}$	40	X	M			Total Pressure
PITo-A	0-100 psig	0-69 $\frac{N}{cm^2}$	40	X				
PITo-B	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
PTITo	0-100 psig	0-69 $\frac{N}{cm^2}$	20					Total Pressure
PTe5-A	0-100 psig	0-69 $\frac{N}{cm^2}$	40		B			
PTe5-B	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
TTe5-A	220-710°R	122-394°K	10		M			2.5 in. (6.4 cm) CR/AL Thermocouple
TTe5-B	220-710°R	122-394°K	10					2.5 in. (6.4 cm) CR/AL Thermocouple
PTTe5-A	0-100 psig	0-69 $\frac{N}{cm^2}$	20					Total Pressure
PTTe5-B	0-100 psig	0-69 $\frac{N}{cm^2}$	20					Total Pressure
PTeOi	0-100 psig	0-69 $\frac{N}{cm^2}$	40					
TTeOi	220-710°R	122-394°K	10					2.75 in. (7 cm) CR/AL Thermocouple
ΔPTeO	Δ50 psi	Δ34 $\frac{N}{cm^2}$	40					

TABLE X (cont.)

Power Transmission Instrumentation

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart**	H.F. Tape	Visual Gauge	Remarks
PBH	0-1000 psig	0-689 $\frac{N}{cm^2}$	10		M			
ΔPBH	Δ1000 psi	Δ689 $\frac{N}{cm^2}$	10		M			Δ(PBH-PGGT)
TBH	0-600°R	0-333°K	20		M			CR/AL Thermocouple
TB1-A	0-600°R	0-333°K	10		M			CR/AL Thermocouple
TB1-B	0-600°R	0-333°K	10					CR/AL Thermocouple
TB2-A	0-600°R	0-333°K	10		M			CR/AL Thermocouple
TB2-B	0-600°R	0-333°K	10					CR/AL Thermocouple
TB3-A	0-600°R	0-333°K	10		M			CR/AL Thermocouple
TB3-B	0-600°R	0-333°K	10					CR/AL Thermocouple
TB4-A	0-600°R	0-333°K	10		M			CR/AL Thermocouple
TB4-B	0-600°R	0-333°K	10					CR/AL Thermocouple
PGGT	0-500 psig	0-345 $\frac{N}{cm^2}$	10					
PFBV-2	0-500 psig	0-345 $\frac{N}{cm^2}$	20					
PFBV-9	0-1000 psig	0-689 $\frac{N}{cm^2}$	20					
FA1	±8000 lb	±3629 kg	20	X				Main Shaft Axial Thrust
FA2	±8000 lb	±3629 kg	20	X				Main Shaft Axial Thrust
NT-A	0-40000 rpm	0-4189 $\frac{rad}{s}$	40	X	B			
NT-B	0-40000 rpm	0-4189 $\frac{rad}{s}$	40	X	W			
NIT-A	0-20000 rpm	0-2094 $\frac{rad}{s}$	40	X	B			

TABLE X (cont.)

Power Transmission Instrumentation (cont.)

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
NIT-B	0-20000 rpm	0-2094 $\frac{rad}{s}$	40	X	W			
PIBi-A	0-500 psig	0-345 $\frac{N}{cm^2}$	10		M			
PIBi-B	0-500 psig	0-345 $\frac{N}{cm^2}$	10					
TIBi	0-160°R	0-89°K	20		M			2.5 in. (6.4 cm) CR/AL Thermocouple
ΔPIB	Δ500 psi	Δ345 $\frac{N}{cm^2}$	10		M			Δ(PIBi-A - PFIo-A)
PIBOo	0-500 psig	0-345 $\frac{N}{cm^2}$	10					
ΔPIBO	Δ500 psi	Δ345 $\frac{N}{cm^2}$	10		W			Δ(PFD2-A - PIBOo)
PTBi-A	0-500 psig	0-345 $\frac{N}{cm^2}$	20		W			
PTBi-B	0-500 psig	0-345 $\frac{N}{cm^2}$	10					
TTBi	0-160°R	0-89°K	20		M			2.75 in. (7 cm) CR/AL Thermocouple
ΔPTB	Δ500 psi	Δ345 $\frac{N}{cm^2}$	10		GE			Δ(PTBi-A - PITo-A)
PTBOi	0-1000 psig	0-689 $\frac{N}{cm^2}$	10					
ΔPTBO	Δ500 psi	Δ345 $\frac{N}{cm^2}$	10		W			Δ(PTBOi - PTBi-A)
GTPA-X1	0-150g P-P	0-147 $\frac{M}{s^2}$ P-P				X		Inducer Housing Radial Acceleration
GTPA-Y	0-150g P-P	0-147 $\frac{m}{s^2}$ P-P				X		Inducer Housing Vertical Acceleration
GTPA-Z1	0-150g P-P	0-147 $\frac{m}{s^2}$ P-P				X		Inducer Housing Radial Acceleration
GTPA-X2	0-150g P-P	0-147 $\frac{m}{s^2}$ P-P				X		Exhaust Stator Housing Radial Acceleration
GTPA-Z2	0-150g P-P	0-147 $\frac{m}{s^2}$ P-P				X		Exhaust Stator Housing Radial Acceleration

TABLE X (cont.)

Facility Instrumentation

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
PGH2B	0-5000 psig	0-3447 $\frac{N}{cm^2}$					X	
PGH2M-N	0-5000 psig	0-3447 $\frac{N}{cm^2}$	20				X	
PACCV	0-5000 psig	0-3447 $\frac{N}{cm^2}$	10				X	
PHDCV	0-4000 psig	0-2758 $\frac{N}{cm^2}$	10				X	
PHRCV	0-100 psig	0-69 $\frac{N}{cm^2}$	10				X	
PGSMRD-2	0-2000 psig	0-1379 $\frac{N}{cm^2}$	10		M			
PSGM	0-2000 psig	0-1379 $\frac{N}{cm^2}$	20	X	M			
PFT-H10	0-100 psig	0-69 $\frac{N}{cm^2}$	10				X	
PFCTi	0-500 psig	0-345 $\frac{N}{cm^2}$	10				X	
PGPCVPR	0-4000 psig	0-2758 $\frac{N}{cm^2}$	10		M			
PGPCVPRO	0-4000 psig	0-2758 $\frac{N}{cm^2}$	10				X	
PGPCVOo	0-1000 psig	0-689 $\frac{N}{cm^2}$	10		M			
PATPCV	0-1000 psig	0-689 $\frac{N}{cm^2}$	10				X	
PFT-H11E	0-100 psig	0-69 $\frac{N}{cm^2}$	20					
PFTo	0-100 psig	0-69 $\frac{N}{cm^2}$	20					
PFDCV	0-1000 psig	0-689 $\frac{N}{cm^2}$	20					
PFT-H1	0-100 psig	0-69 $\frac{N}{cm^2}$					X	
TBOD-3A	490-915°R	272-508°K					X	CR/AL Thermocouple
TBOD-3B	490-915°R	272-508°K					X	CR/AL Thermocouple
TFVL	0-60°R	0-33°K	20					2.5 in. (6.4 cm) RTT
TFCTi	0-60°R	0-33°K	20					6 in. (15.2 cm) RTT
FMPW	0-5 gpm	0-0.3 $\frac{dm^3}{s}$	20				X	
LTPCV	0-90 deg	0-157 rad	20	X	S			
LDFCV	0-100%	0-100%	20		S			

TABLE X (cont.)

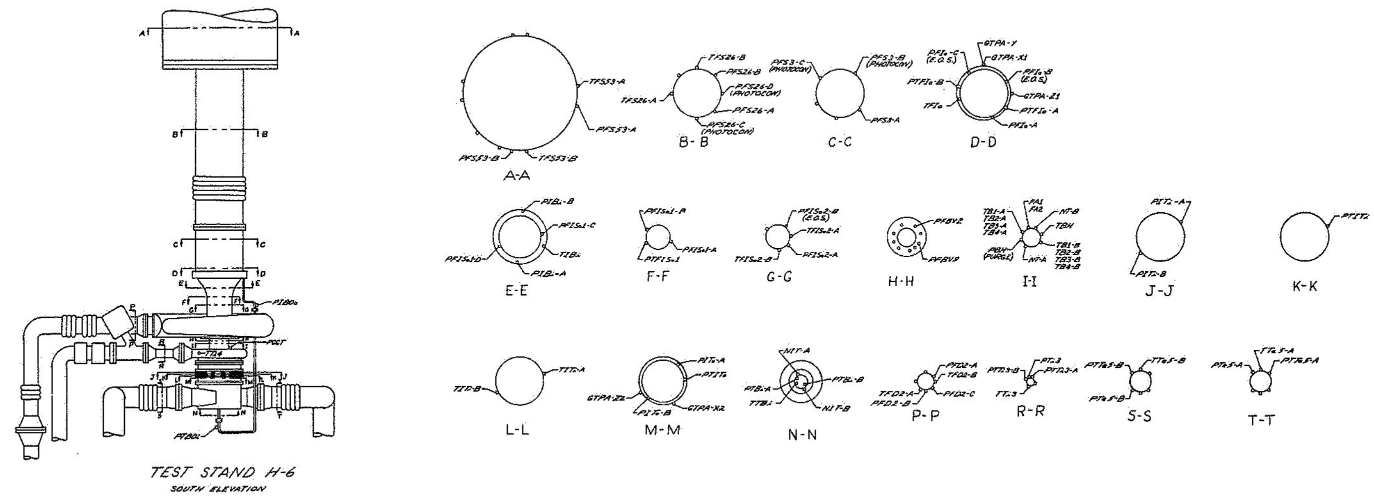
Facility Instrumentation (cont.)

Parameter	Range	Range* (SI Units)	ADC**	Oscillograph	Strip Chart***	H.F. Tape	Visual Gauge	Remarks
LPFCV	0-100%	0-100%	20		S			
LVFCV	0-100%	0-100%	20		S			
LTDV	0-100%	0-100%	20	X	S			
FMVS-A	0-10000 gpm	0-6025 $\frac{dm^3}{s}$	20					
FMVD-A	0-10000 gpm	0-6025 $\frac{dm^3}{s}$	20					
NTV-A	0-40000 rpm	0-4189 $\frac{rad}{s}$	20					
NITV-A	0-20000 rpm	0-2094 $\frac{rad}{s}$	20					
SGPS	---	---	20					
17 Bit T/C	0-24 hr	0-86400s		X		X		Time of Day
PS_1/PS_2	---	---	20	X		X		Switch Trace
TS_1/TS_2	---	---	20					Switch Trace
OSTM	---	---		X				Switch Trace
OSTI	---	---		X				Switch Trace
PTi-Max	---	---		X				Switch Trace
PHD-MIN	---	---		X				Switch Trace
PFD-MAX	---	---		X				Switch Trace
NT-MIN	---	---		X				Switch Trace
RSD	---	---		X				Switch Trace

*The pressure values $(\frac{N}{cm^2})$ shown in this column are gauge pressure.

**The numbers in this column are the sampling rate in samples per second used by the Analog to Digital System

***The letters in this column represent types of recorders: B = Brown 153X; W = Westronics D-11A/Y; M = Moseley 680; S = Sanborn 1584; GE = General Electric



PUMP

SYM.	DESCRIPTION	SECT.
PFT	PRESSURE - FUEL TANK V-H11	—
TFT	TEMPERATURE - FUEL TANK V-H11	—
FMFS	FLOW METER - FUEL SUCTION	—
PFMFS	PRESSURE - FUEL SUCTION FLOW METER	—
TFMFS	TEMPERATURE - FUEL SUCTION FLOW METER	—
PFS53	PRESSURE - FUEL SUCTION 53" ABOVE INLET	A-A
TFS53	TEMPERATURE - FUEL SUCTION 53" ABOVE INLET	A-A
PFS26	PRESSURE - FUEL SUCTION 26" ABOVE INLET	B-B
TFS26	TEMPERATURE - FUEL SUCTION 26" ABOVE INLET	B-B
PFS3	PRESSURE - FUEL SUCTION 3" BELOW INLET	C-C
TFS3	TEMPERATURE - FUEL SUCTION 3" BELOW INLET	C-C
PFIo	PRESSURE - FUEL INDUCER OUTLET	D-D
TFIo	TEMPERATURE - FUEL INDUCER OUTLET	D-D
PTFIo	PRESSURE, TOTAL - FUEL INDUCER OUTLET	D-D
PFISo1	PRESSURE - FUEL INDUCER STATOR OUTLET	E-E F-F
PTFISo1	PRESSURE, TOTAL - FUEL INDUCER STATOR OUTLET	F-F
PFISo2	PRESSURE - FUEL INDUCER STATOR OUTLET	G-G
TFISo2	TEMPERATURE - FUEL INDUCER STATOR OUTLET	G-G
PFD2	PRESSURE - FUEL DISCHARGE 2" BELOW OUTLET	P-P
TFD2	TEMPERATURE - FUEL DISCHARGE 2" BELOW OUTLET	P-P
FMFD	FLOW METER - FUEL DISCHARGE	—
PFMFD	PRESSURE - FUEL DISCHARGE FLOW METER	—
TFMFD	TEMPERATURE - FUEL DISCHARGE FLOW METER	—

TURBINE

SYM.	DESCRIPTION	SECT.
PGTDOi	PRESSURE - TURBINE DRIVE GAS ORIFICE INLET	—
TGTDOi	TEMPERATURE - TURBINE DRIVE GAS ORIFICE INLET	—
ΔPGTDO	PRESSURE DROP - TURBINE DRIVE GAS ORIFICE	—
PTi 3	PRESSURE - TURBINE INLET 3" ABOVE INLET	R-R
TTi 3	TEMPERATURE - TURBINE INLET 3" ABOVE INLET	R-R
PTTi 3	PRESSURE, TOTAL - TURBINE INLET 3" ABOVE INLET	R-R
TTi 4	TEMPERATURE - TURBINE INLET 4" BELOW INLET	—
PITi	PRESSURE - INDUCER TURBINE INLET	J-J
TITi	TEMPERATURE - INDUCER TURBINE INLET	L-L
PTITi	PRESSURE, TOTAL - INDUCER TURBINE INLET	K-K
PITo	PRESSURE - INDUCER TURBINE OUTLET	M-M
PTITo	PRESSURE, TOTAL - INDUCER TURBINE OUTLET	M-M
PTe 5	PRESSURE - TURBINE EXHAUST 5" BELOW OUTLET	S-S T-T
TTe 5	TEMPERATURE - TURBINE EXHAUST 5" BELOW OUTLET	S-S T-T
PTTe 5	PRESSURE, TOTAL - TURBINE EXHAUST 5" BELOW OUTLET	S-S T-T
PTe Oi	PRESSURE - TURBINE EXHAUST ORIFICE INLET	—
TTe Oi	TEMPERATURE - TURBINE EXHAUST ORIFICE INLET	—
ΔPTe O	PRESSURE DROP - TURBINE EXHAUST ORIFICE	—

POWER TRANSMISSION

SYM.	DESCRIPTION	SECT.
PBH	PRESSURE - BEARING HOUSING	I-I
TBH	TEMPERATURE - BEARING HOUSING	I-I
TB1	TEMPERATURE - PUMP END ROLLER BEARING	I-I
TB2	TEMPERATURE - PUMP END THRUST BEARING	I-I
TB3	TEMPERATURE - TURBINE END THRUST BEARING	I-I
TB4	TEMPERATURE - TURBINE END ROLLER BEARING	I-I
PFGT	PRESSURE - TURBINE FIRST STAGE CAVITY	—
PFBV	PRESSURE - FUEL IMPELLER BACK VANE	H-H
FA1	THRUST, AXIAL - MAIN STAGE TOWARD PUMP	I-I
FA2	THRUST, AXIAL - MAIN STAGE TOWARD TURBINE	I-I
NT	SPEED - MAIN SHAFT	I-I
NIT	SPEED - INDUCER SHAFT	N-N
PIBi	PRESSURE - INDUCER BEARING INLET	E-E
TIBi	TEMPERATURE - INDUCER BEARING INLET	E-E
PIBOo	PRESSURE - INDUCER BEARING ORIFICE OUTLET	—
ΔPIBO	PRESSURE DROP - INDUCER BEARING ORIFICE	—
PTBi	PRESSURE - TURBINE BEARING INLET	N-N
TTBi	TEMPERATURE - TURBINE BEARING INLET	N-N
FMTB	FLOW METER - TURBINE BEARING	—
PTBOi	PRESSURE - TURBINE BEARING ORIFICE INLET	—
ΔPTBO	PRESSURE DROP - TURBINE BEARING ORIFICE	—
GTPA-X	ACCELERATION, TURBOPUMP - HORIZONTAL PLANE	D-D M-M
GTPA-Y	ACCELERATION, TURBOPUMP - VERTICAL PLANE	
GTPA-Z	ACCELERATION, TURBOPUMP - HORIZONTAL PLANE	D-D M-M
YTPA	DISPLACEMENT, TURBOPUMP - VERTICAL PLANE	
ZTPA	DISPLACEMENT, TURBOPUMP - HORIZONTAL PLANE	

Figure 97. - NPSP Demonstration TPA Instrumentation Location.

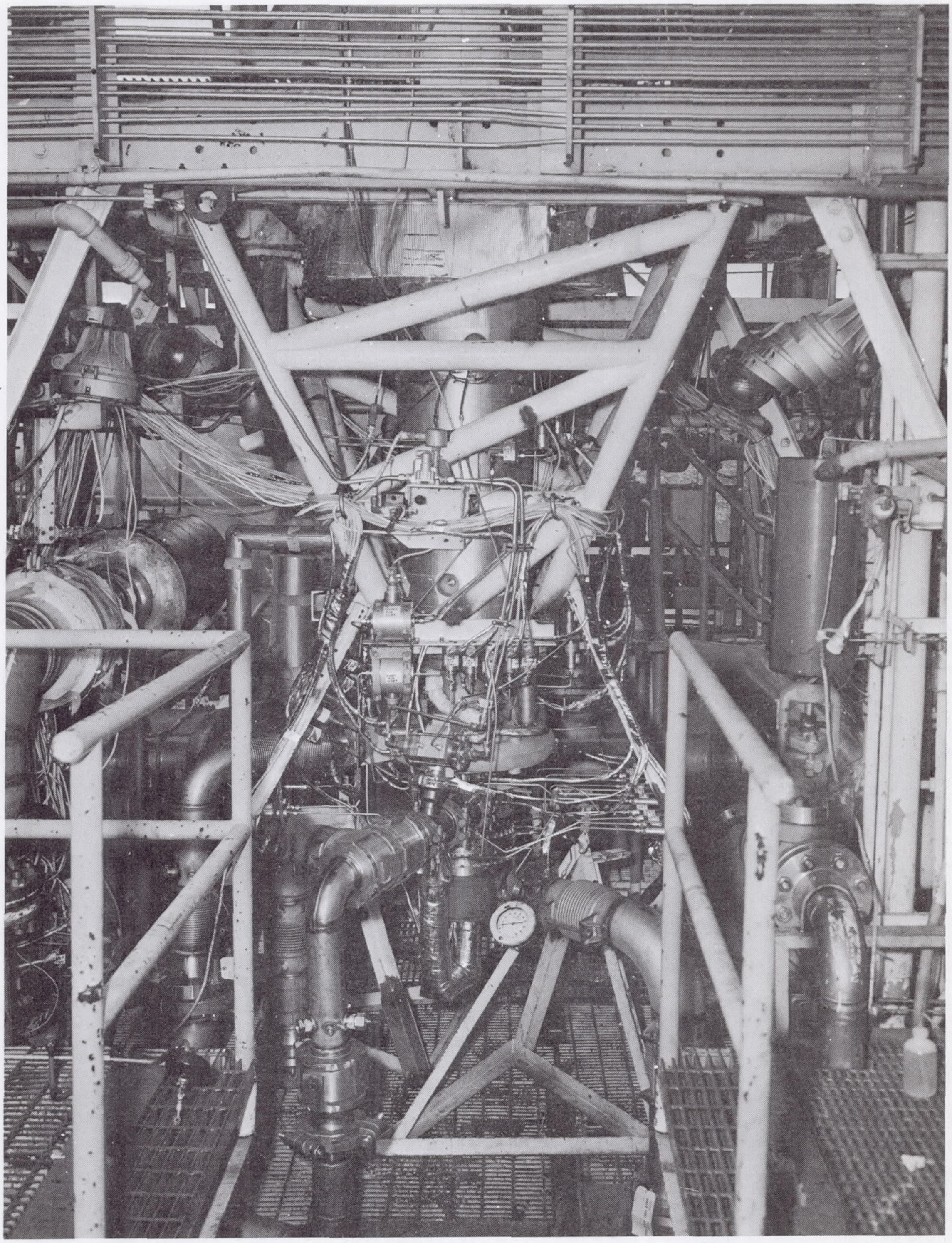


Figure 98. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

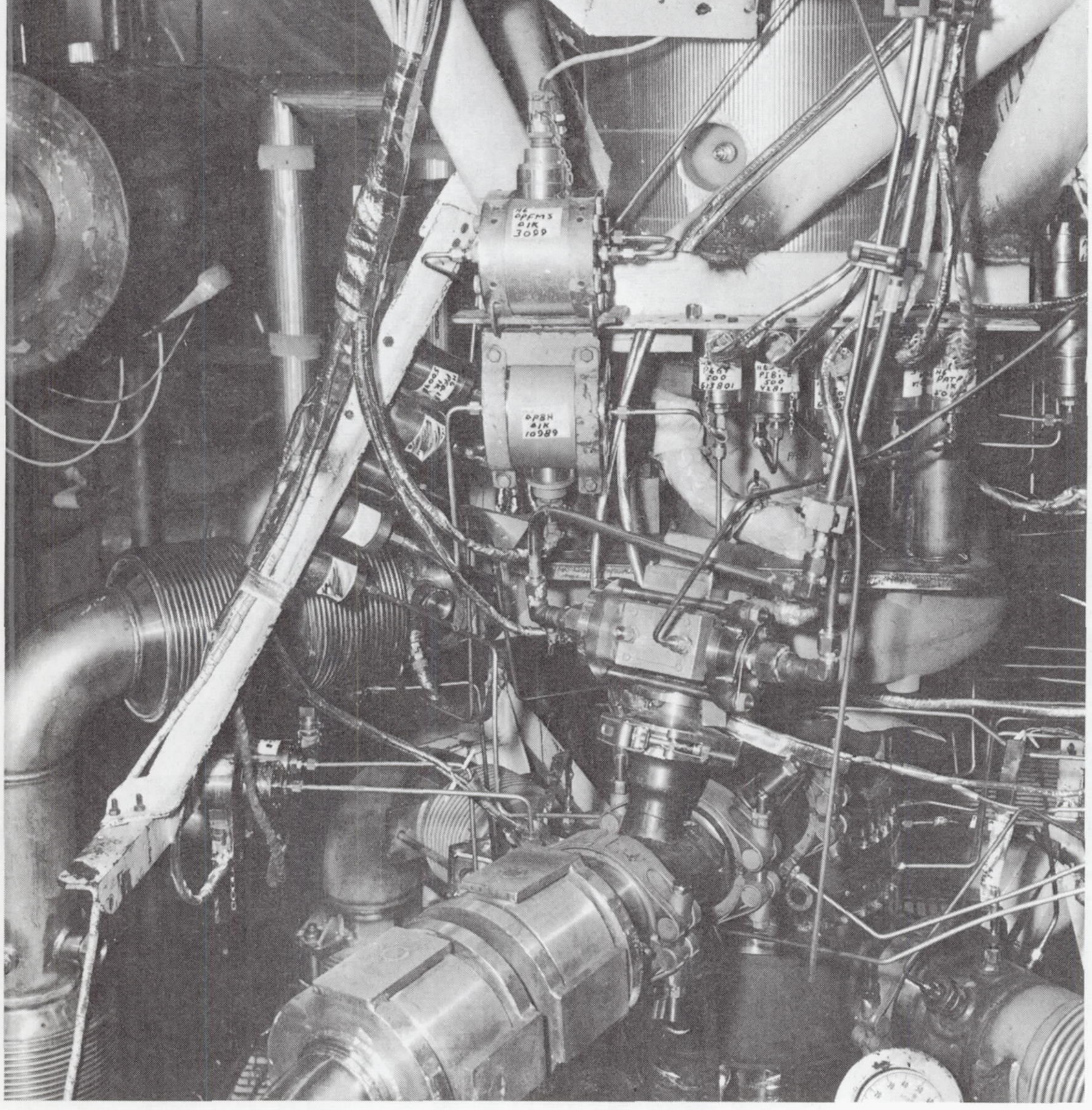


Figure 99. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

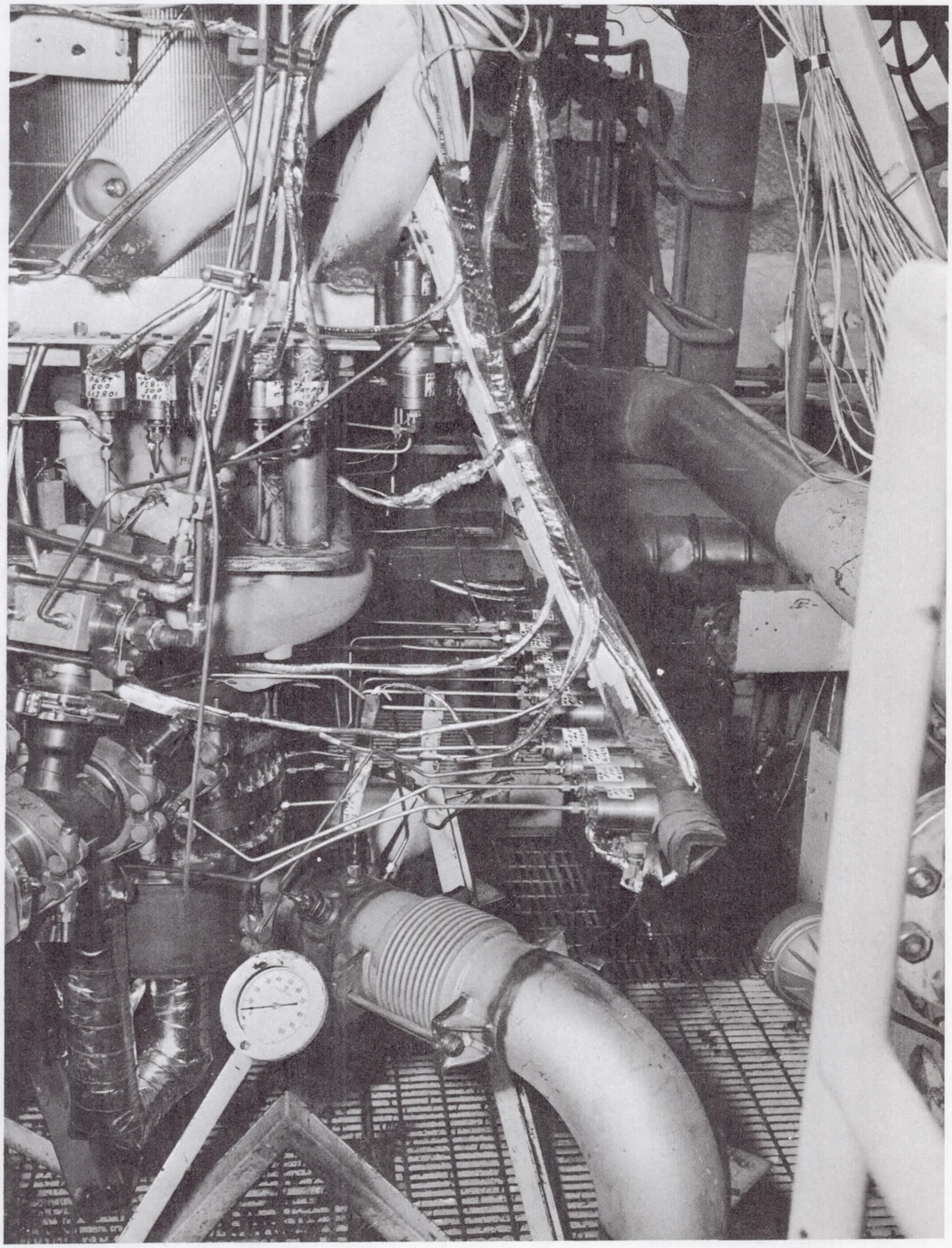


Figure 100. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

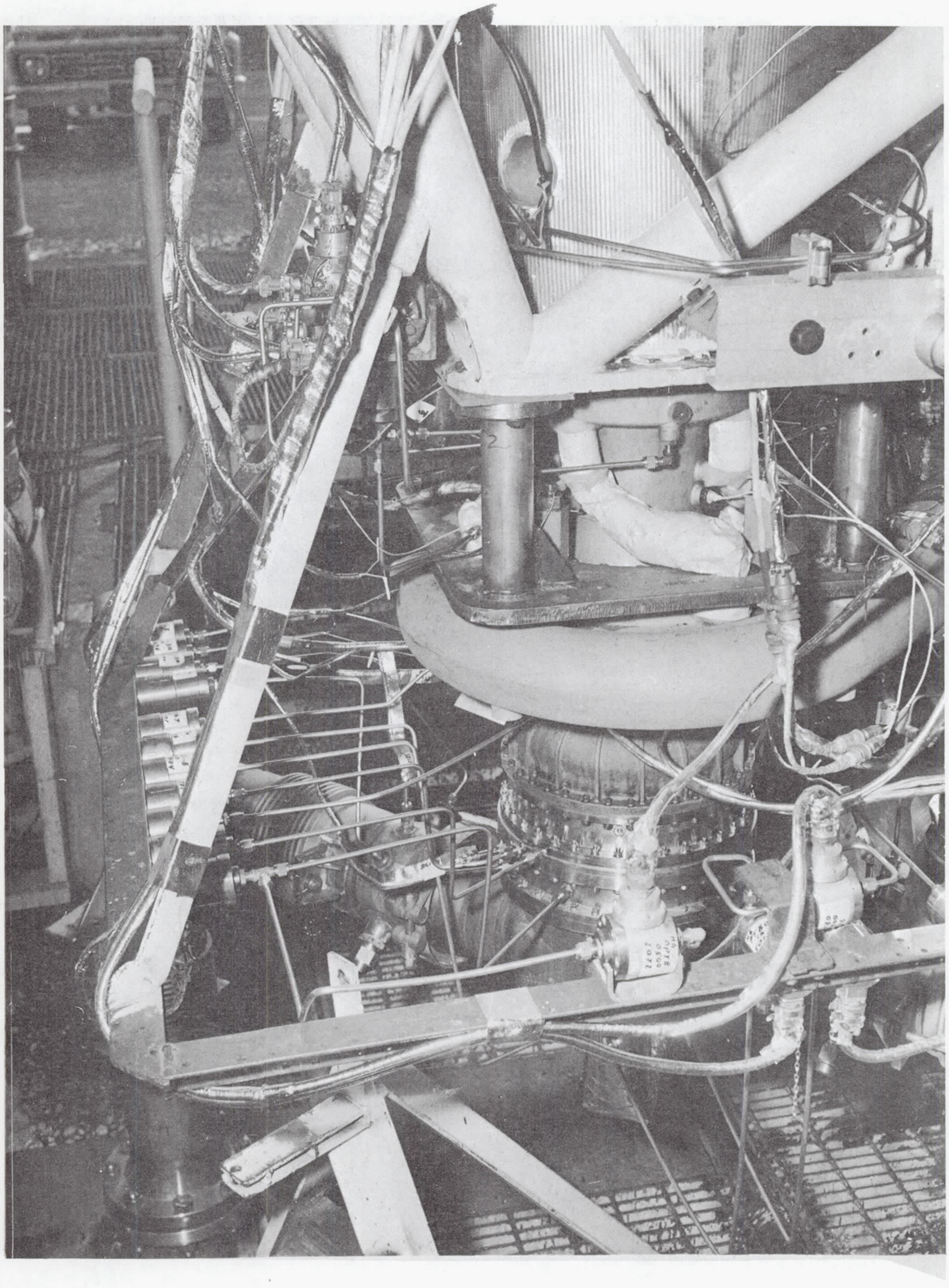


Figure 101. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

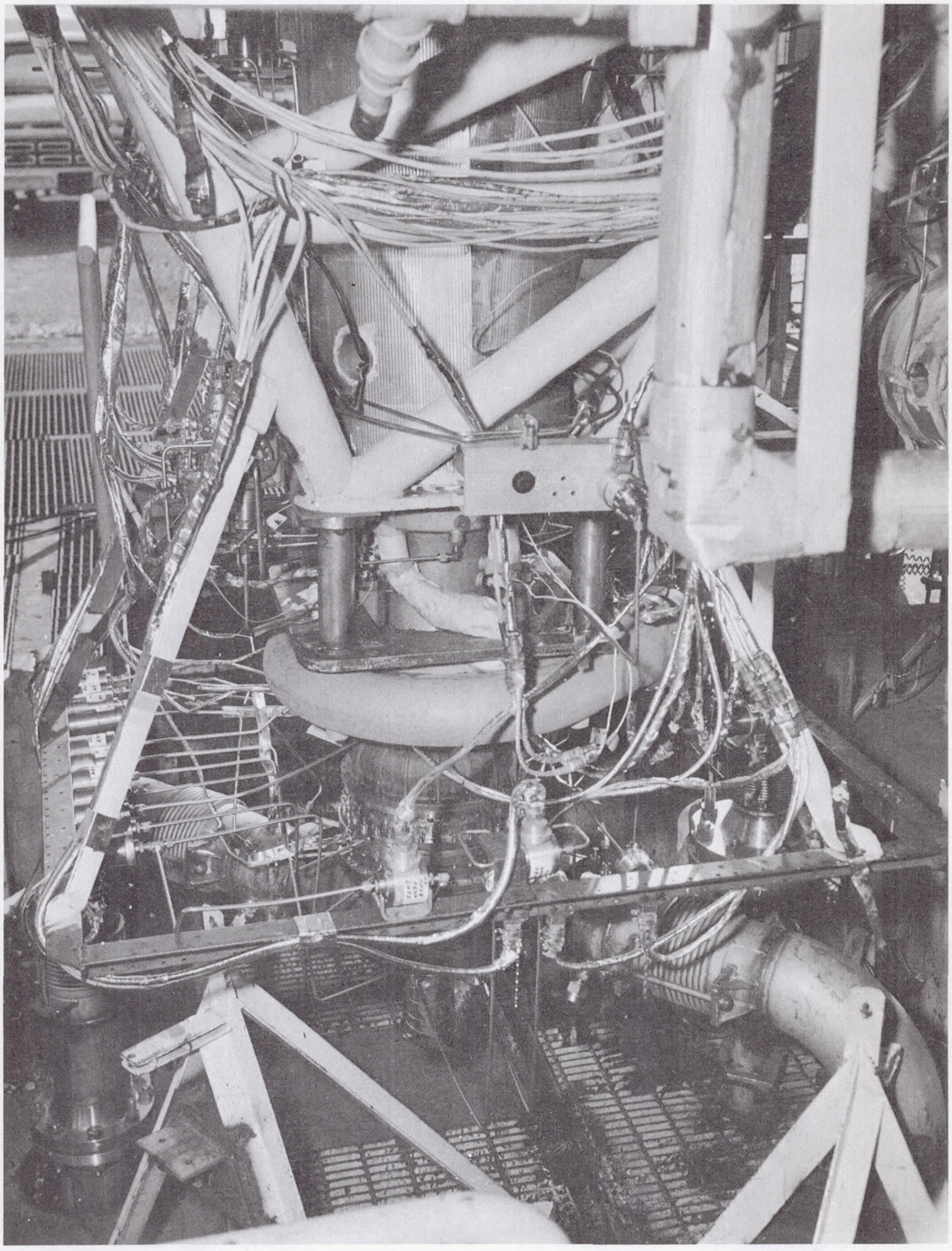


Figure 102. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

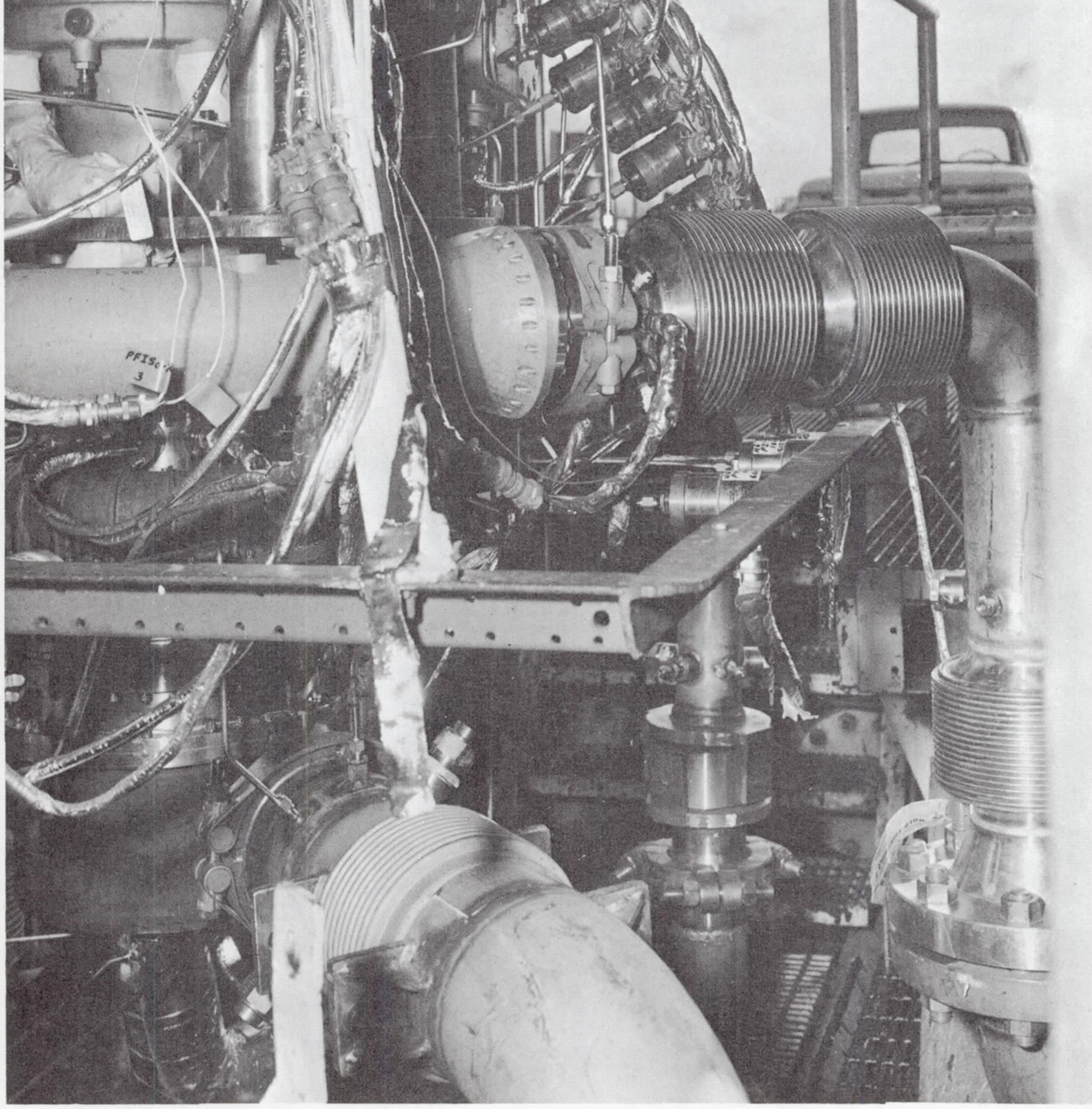


Figure 103. - View of Twin-Spool TPA S/N 99019, Pre-Test No. 1261-D01-OP-001.

The strip charts and visual gauges were used for visual settings of the turbopump operating conditions. The analog-to-digital data obtained during each test was stored on magnetic tape.

Raw data from the analog-to-digital system was reduced and converted to engineering units after each test by utilizing the turbopump data reduction program (Computer Job 304). These data were made available to the Project Engineer, who reviewed the pertinent data before each test as well as prior to the removal of the test unit from the test stand.

E. TEST SUMMARIES

The following four different kinds of tests were conducted within the seven test programs, wherein liquid hydrogen was pumped and gaseous hydrogen was used to drive the turbine:

- Head-capacity traverses at constant speed and NPSP
- NPSP traverse at constant speed and flow rate
- Head-capacity traverses at off-nominal turbine pressure ratios
- Transient response evaluation

The transient tests were designed to simulate start ramps that are comparable with chemical engine starts. One partial-speed checkout test was conducted prior to operating at the 22,000 rpm (2300 rad/s) nominal shaft speed.

Table XI is a summary of the testing conducted.

1. Test No. 1261-D01-OP-001

This test was conducted at approximately half of the nominal speed for the purpose of checking out both the turbopump and the facility prior to full-power operation. Head rise-flow rate traverses, including main-stage stall, were made at both positive and zero NPSP. Matching of the actual and predicted operating conditions was very good.

2. Test No. 1261-D01-OP-002

This was an H-Q traverse test at full speed. The flow rate was varied from 70 lb/sec (31.8 Kg/s) to 45 lb/sec (20.4 Kg/s). It was not possible to operate at 77 lb/sec (34.9 Kg/s) because of turbine drive system limitations. One H-Q traverse was made at a tank NPSP of 20 psi (14 N/cm^2), and one was made at approximately 5 psi (3 N/cm^2). Data was taken at 19,000 rpm (1990 rad/s) at a tank NPSP of approximately 1 psi (0.7 N/cm^2) because the available turbine drive system power restricted the speed to this value.

TABLE XI

TESTING SUMMARY

Test Number	Date	ADC Time (sec)	Tank NPSP (psi)	Tank NPSP (N/cm^2)	Main Shaft Speed (rpm)	Main Shaft Speed (rad/s)	Pump Flow-rate (lb-sec)	Pump Flow-rate (kg/s)	Pump Flow Parameter (gal/rev)	Pump Flow Parameter (dm^3/rad)	Remarks
1261-D01-OP-001	1-8-69	170.801	9.53	6.57	10934	1145.0	31.68	14.37	0.301	0.181	
		232.763	9.50	6.55	10943	1145.9	36.41	16.52	0.346	0.208	
		265.906	9.96	6.87	10942	1145.8	40.10	18.19	0.382	0.230	
		319.222	8.46	5.83	10936	1145.2	25.94	11.77	0.246	0.148	
		365.333	8.83	6.09	10940	1145.6	20.12	9.13	0.192	0.116	
		428.736	6.55	4.52	10948	1146.5	14.16	6.42	0.137	0.083	
		462.599	7.50	5.17	10915	1143.0	10.20	4.63	0.101	0.061	Low Speed Stall Test
		580.965	0.13	0.09	10949	1146.6	31.75	14.40	0.301	0.181	
		639.634	0.00	0.00	10956	1147.3	36.41	16.52	0.345	0.208	
		677.305	0.17	0.12	10946	1146.3	39.76	18.03	0.379	0.228	
		728.460	0.00	0.00	10939	1145.5	25.81	11.71	0.245	0.148	
		771.895	9.3% Vap	9.3% Vap	10961	1147.8	20.11	9.12	0.191	0.115	
		820.888	9.2% Vap	9.2% Vap	10952	1146.9	14.38	6.52	0.138	0.083	
		854.751	4.9% Vap	4.9% Vap	10743	1125.0	10.24	4.64	0.104	0.063	Low Speed Stall Test
1261-D01-OP-002	1-10-69	81.709	25.47	17.56	18005	1885.5	50.86	25.07	0.292	0.176	
		139.554	20.29	13.99	21868	2290.0	62.52	28.36	0.296	0.178	
		177.945	20.83	14.36	21598	2261.7	69.83	31.67	0.336	0.202	
		222.616	20.59	14.20	21981	2301.8	54.54	24.74	0.256	0.154	
		250.406	20.57	14.18	21928	2296.3	45.32	20.56	0.214	0.129	
		288.592	21.64	14.92	21382	2239.1	62.15	28.19	0.300	0.181	
		335.527	4.64	3.20	21363	2237.1	61.37	27.84	0.312	0.188	
		385.240	5.89	4.06	20839	2182.3	51.33	23.28	0.254	0.153	
		411.384	7.05	4.86	21472	2248.5	44.63	20.24	0.215	0.130	
		438.454	5.01	3.45	19338	2025.1	55.43	25.14	0.296	0.178	
		461.509	0.41	0.28	19048	1994.7	54.32	24.64	0.295	0.178	
		499.181	1.13	0.78	19273	2018.3	47.71	21.64	0.256	0.154	
		525.530	1.12	0.77	19912	2085.2	41.15	18.67	0.214	0.129	
		561.143	12.04	8.30	16297	1706.6	60.31	27.36	0.389	0.234	

TABLE XI (cont.)

Test Number	Date	ADC Time (sec)	Tank NPSP (psi)	Tank NPSP (N/cm^2)	Main Shaft Speed (rpm)	Main Shaft Speed (rad/s)	Pump Flow-Rate (lb/sec)	Pump Flow-rate (kg/s)	Pump Flow Parameter (gal/rev)	Pump Flow Parameter (dm^3/rad)	Remarks
1261-D01-OP-003	1-14-69	73.322	6 sec Start Ramp - Refer to Section III and Figure 58								
		110.110	14.7% Vap	14.7% Vap	22026	2306.6	76.03	34.48	0.364	0.219	
		to	to	to	to	to	to	to	to	to	NPSP Ramp
		153.597	21.13	14.57	22038	2307.8	76.52	34.71	0.364	0.219	
		186.534	21.92	15.11	22024	2306.3	64.75	29.37	0.304	0.183	
		to	to	to	to	to	to	to	to	to	NPSP Ramp
		256.936	43.2% Vap	43.2% Vap	22100	2314.3	63.35	28.74	0.300	0.181	
1261-D01-OP-003A	1-14-69	153.683	11.0% Vap	11.0% Vap	11231	1176.1	36.13	16.39	0.333	0.201	Flow from Turbine Inlet Line Bypassing Turbopump into Turbine Exhaust Line.
1261-D01-OP-004	1-17-69	1325.936	3 sec Start Ramp - Refer to Section III and Figure 59								
1261-D01-OP-004A	1-17-69	64.814	3 Sec Start Ramp - Refer to Section III and Figure 60								
		168.711	9.7% Vap	9.7% Vap	22003	2304.1	69.83	31.67	0.332	0.200	
		246.113	7.8% Vap	7.8% Vap	21980	2301.7	53.94	24.47	0.255	0.154	
		335.144	20.08	13.84	21952	2298.8	45.33	20.56	0.214	0.129	
		to	to	to	to	to	to	to	to	to	NPSP Ramp
		428.088	10.4% Vap	10.4% Vap	20944	2193.3	43.33	19.65	0.215	0.130	
1261-D01-OP-005	1-21-69	133.512	4.4% Vap	4.4% Vap	21997	2303.5	75.26	34.14	0.365	0.220	
		189.504	0.41	0.28	21976	2301.3	69.32	31.44	0.333	0.201	
		255.378	8.8% Vap	8.8% Vap	21896	2292.9	61.61	27.95	0.295	0.178	
		292.020	0.00	0.00	21930	2296.5	53.68	24.35	0.256	0.154	
		360.569	3.3% Vap	3.3% Vap	21930	2296.5	44.80	20.32	0.214	0.129	

TABLE XI (cont.)

Test Number	Date	ADC Time (sec)	Tank NPSP (psi)	Tank NPSP (N/cm^2)	Main Shaft Speed (rpm)	Main Shaft Speed (rad/s)	Pump Flow-rate (lb/sec)	Pump Flow-rate (kg/s)	Pump Flow Parameter (gal/rev)	Pump Flow Parameter (dm^3/rad)	Remarks
1261-D01-OP-006	1-23-69	122.982	11.1% Vap	11.1% Vap	21956	2299.2	75.18	34.10	0.366	0.221	
		171.152	9.3% Vap	9.3% Vap	21958	2299.4	69.38	31.47	0.334	0.201	
		240.319	11.2% Vap	11.2% Vap	21897	2293.0	61.73	28.00	0.296	0.178	
		302.899	12.3% Vap	12.3% Vap	21857	2288.9	53.44	24.24	0.256	0.154	
		360.538	11.7% Vap	11.7% Vap	21916	2295.0	45.06	20.44	0.216	0.130	
		446.173	12.0% Vap	12.0% Vap	19005	1990.2	38.93	17.66	0.215	0.130	
		539.219	16.8% Vap	16.8% Vap	15075	1578.7	31.00	14.06	0.215	0.130	
1261-D01-OP-007	1-28-69	152.700	0.00	0.00	10825	1133.6	41.83	18.97	0.417	0.251	
		235.042	3.8% Vap	3.8% Vap	15131	1584.5	57.03	25.87	0.412	0.248	
		333.646	3.5% Vap	3.5% Vap	16952	1775.2	62.19	28.21	0.398	0.240	
		455.615	0.79	0.54	22033	2307.3	44.20	20.05	0.212	0.128	
		to	to	to	to	to	to	to	to	to	High Speed Stall Test
		502.652	0.67	0.46	22078	2312.0	24.50	11.11	0.122	0.074	

3. <u>Test No. 1261-D01-OP-003</u>

The 6 sec start ramp at zero NPSP was run in this test. The NPSP ramps at the 76 lb/sec (34 Kg/s) and 64 lb/sec (29 Kg/s) also were made. The test was terminated when the inducer speed exceeded 11,000 rpm (1152 rad/s). The turbopump was restarted (Test No. 1261-D01-OP-003A) following the shutdown. A blown burst disc in the turbine supply line caused the drive gas to be bypassed into the turbine exhaust system, and the turbopump would not operate. above 12,000 rpm (1257 rad/s).

4. <u>Test No. 1261-D01-OP-004</u>

This test consisted of a 3 sec start ramp at a NPSP of 20 psi (14 N/cm^2). The turbopump was shutdown and restarted with a 3 sec ramp at an NPSP of 1 psi (0.7 N/cm^2) (Test No. 1261-D01-OP-004A). The turbopump was operated at zero NPSP at flow rates of 70 lb/sec (32 Kg/s) and 54 lb/sec (24 Kg/s). The NPSP ramp at 45 lb/sec (20 Kg/s) also was made during Test No. 1261-D01-OP-004A.

5. <u>Test No. 1261-D01-OP-005</u>

This test consisted of an H-Q traverse at zero NPSP with the effective area of the turbine exhaust system reduced by 10% by placing an orifice in the turbine exhaust line.

6. <u>Test No. 1261-D01-OP-006</u>

This test was a duplication of Test No. 1261-D01-OP-005, with the effective area of the exhaust system reduced by 20%. The turbopump also was operated at 19,000 rpm (1990 rad/s), with 39 lb/sec (18 Kg/s) flow rate and 15,000 rpm (1571 rad/s) with 31 lb/sec (14 Kg/s) flow rate. The NPSP at these two conditions was zero.

7. <u>Test No. 1261-D01-OP-007</u>

During this test, the turbopump was operated at a high flow parameter of 0.41 gal/rev (0.23 dm^3/rad) at zero NPSP. The speed was limited to 15,000 rpm (1571 rad/s) by the turbine drive system. The location of the main-stage stall at 22,000 rpm (2304 rad/s) and NPSP = 0.7 psi (0.5 N/cm^2) also was established during this test.

VII. COMPUTER PROGRAM AND REFINEMENT

A digital computer program was developed for the prediction of Twin-Spool Turbopump operating characteristics during steady-state or transient operation with hydrogen as the turbine drive gas and pumped fluid. Verification of the analytical model was demonstrated by comparing the analytical performance predictions with the experimental data obtained from the Twin-Spool Turbopump testing discussed previously.

This program, which is in FORTRAN IV language, is suitable for operation on the IBM 360 system machines with at least 100,000 bytes of core available for program use. Hydrogen properties subroutines are incorporated into the program to provide hydrogen property data based upon the thermodynamic state of the fluids in the inducer, pump, and turbines.

The analytical model is suitable for use with twin-spool turbopumps for which the steady-state characteristic curves (see Figures No. 104 through No. 107) have been predicted or determined from test data.

A provision for a transient solution of the inducer suction line flow conditions based upon waterhammer theory has been incorporated into the program as an option for transient cases.

Computed data always is supplied by this program as printed digital output. In addition, a program option provides for supplying digital data to a file for graphical presentation depending upon the particular computer facility.

A discussion of the analytical model, computer program details, results, and an example case follows.

A. ANALYTICAL MODEL

The approach selected in formulating the computer model for this turbopump system was one based upon the use of over-all characteristic curves depicting the performance of each turbopump component. It is believed that this substantially reduced both the program complexity and its length because the data presented in each characteristic curve could have required one or more programs to generate.

1. Major Assumptions

The following are the major assumptions applied in this analysis:

a. Main turbine mass flow rate equals inducer turbine mass flow rate.

Turbines

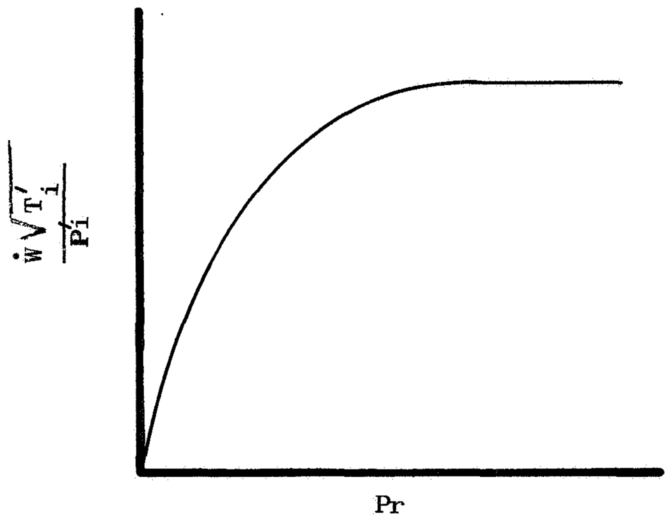


Figure 104: Main Turbine and Inducer Turbine Flow Parameter Curves

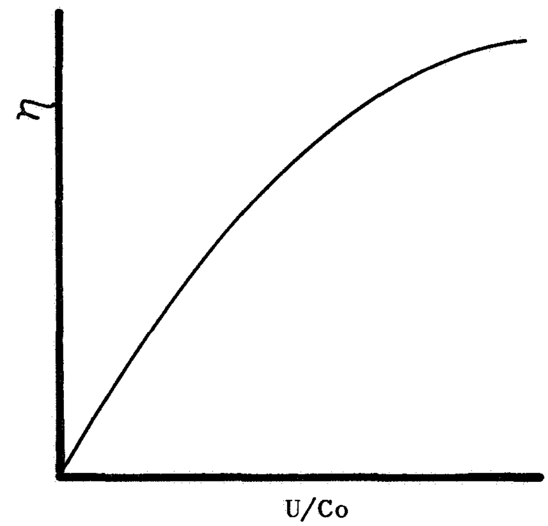


Figure 105: Main Turbine and Inducer Turbine Efficiency Curves

Pump or Inducer

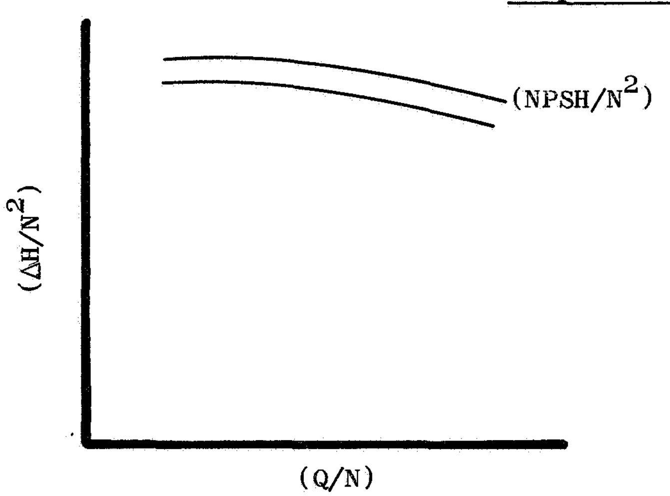


Figure 106: Pump and Inducer Normalized Head Rise Curves

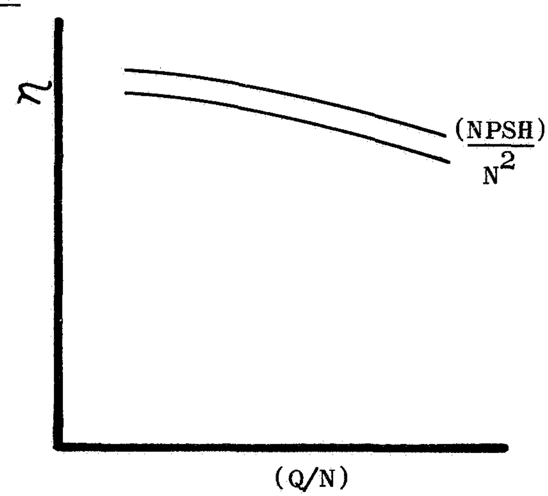


Figure 107: Pump and Inducer Efficiency Curves

b. The flow in the inducer and pump components is incompressible. This assumption does not exclude the computation of density at each station of the pump system.

c. The flow in all of the components is single-phase.

d. Steady-state characteristic data can be used to adequately represent the system in a quasi-steady-state solution.

e. Steady-state conditions exist initially for transient solutions.

f. Bearing friction is negligible.

g. Incompressible flow is adequate to describe the turbine exhaust system.

2. Characteristic Curves

The following characteristic curves are used to represent the performance of the turbopump components:

a. Main Turbine Flow Parameter Curve,

$$\left(\frac{\dot{W}\sqrt{T'_i}}{P'_i}\right)_{mT} = \text{function of main turbine total-to-total pressure ratio, Figure No. 104.}$$

b. Main Turbine Efficiency Curve,

η'_{mT} = function of velocity ratio, U/C_o', where C_o' is the isentropic spouting velocity based upon total-to-total pressure ratio, Figure No. 105.

c. Inducer Turbine Flow Parameter Curve,

$$\left(\frac{\dot{W}\sqrt{T'_i}}{P'_i}\right)_{IT} = \text{function of inducer turbine total-to-static pressure ratio, Figure No. 104.}$$

d. Inducer Turbine Efficiency Curve,

η_{IT} = function of velocity ratio, U/C_o, where C_o is the isentropic spouting velocity based upon total-to-static pressure ratio, Figure No. 105.

e. Pump normalized head-rise curve $(\Delta H/N^2)_p$ = function of $(Q/N)_p$, Figure No. 106. The head rise also is a function of suction conditions ($NPSH/N^2$); therefore, several curves are presented and are tabulated for the computer model.

f. Pump efficiency, η_P = function of $(Q/N)_p$, Figure No. 107. Also, efficiency is related to suction conditions and is presented as a function of $NPSH/N^2$.

g. Inducer normalized head rise, $(\Delta H/N^2)_I$ = function of $(Q/N)_I$, Figure No. 106.

i. Inducer efficiency, η_I = function of $(Q/N)_I$, Figure No. 107.

3. Basic Computational Sequence

Two primary program options are illustrated on Figure No. 108, which is the basic computational sequence used in the computer program. The first option is one where the variation of main shaft speed with time is input while the second option is based upon a time-dependent selection of turbine inlet pressure. The computational sequence for steady-state cases is the same as for the first point of transient cases. Several iterative loops are required to close within iteration limits for the first time-point of transient cases and for all steady-state cases. The primary iteration loops of the program and the method for obtaining covergence are as follows:

a. The main turbine torque equals the main pump torque (turbine inlet pressure option only). The main shaft speed is corrected by the relationship

$$N_{m,\ (n+1)} = N_{m,\ n} \left(\frac{SHP_T}{SHP_P} \right)^{1/3} \qquad \text{Eq. (1)}$$

until convergence, within limits, is accomplished (n = iteration number).

b. The main turbine flow rate equals the inducer turbine flow rate. The main turbine pressure ratio is corrected by numerically evaluating the rates of change of the main and inducer turbine flow rates with

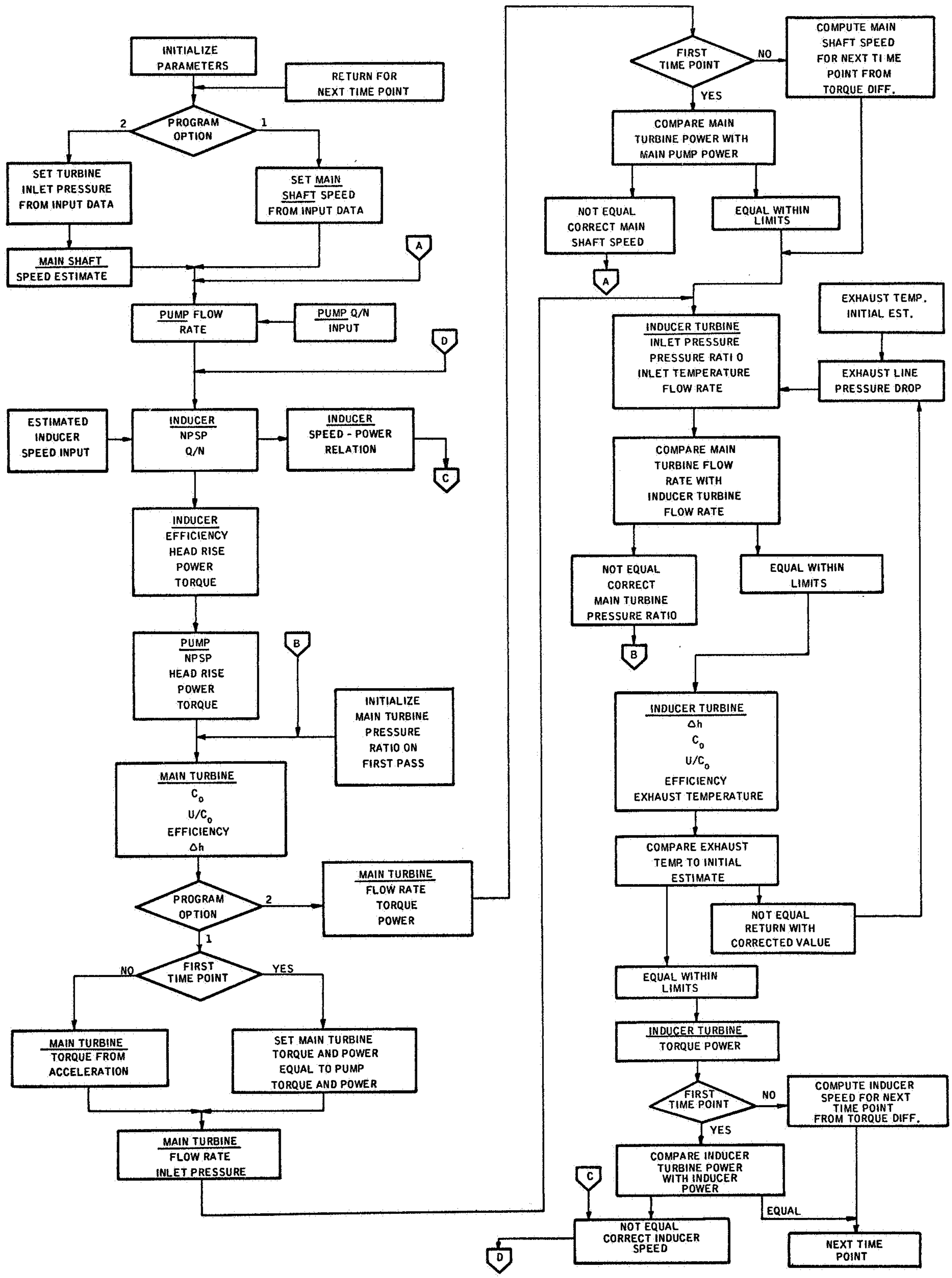


Figure 108. - Primary Computational Sequence.

the main turbine pressure ratio as well as obtaining a simultaneous solution of these two relationships upon a finite difference basis to obtain a corrected main turbine pressure ratio. This method is repeated until convergence is achieved. The details of this pressure ratio correction technique are given in Section VII,C.

c. The inducer turbine torque equals the inducer torque. Once the inducer flow rate has been established, the relationship between inducer speed and torque is ascertained from the inducer normalized head-rise and efficiency curves (subprogram SHPIN). This relationship then is used to correct inducer speed until convergence of the iteration loop is accomplished.

The limits of convergence for the iterative solutions are 0.1%.

For transient cases, the matching of inducer and main turbine flow rates is required after the first time point. Main-stage speed or torque, depending upon which program option is being exercised, is determined from a finite difference solution of one of the following time-dependent equations for time points other than the first:

$$N_{m,\ (t + \Delta t)} = N_{m,t} + \frac{(720.)(\Delta t)}{2\pi I} (\tau_{turbine} - \tau_{pump})\ (P_{Ti}\ \text{input}) \quad \text{Eq. (2)}$$

$$\tau_{turbine} = \tau_{pump} + \frac{2\pi I}{(720.)(\Delta t)} (N_{(t + \Delta t)} - N_t)\ (N\ \text{input}) \quad \text{Eq. (3)}$$

Similarly, inducer speed is determined for successive time points from the relationship

$$N_{I,\ (t + \Delta t)} = N_{I,\ t} + \frac{(720.)(\Delta t)}{2\pi I} (\tau_{turbine} - \tau_{inducer}) \quad \text{Eq. (4)}$$

The time increment Δt for the transient solutions is governed by the wave period in the suction line if the waterhammer solution is being used. Otherwise, the time increment can be input.

All of the detailed equations involved in the analysis are included in Section VII, C.

B. COMPUTER PROGRAM

The computer program is divided into a Main Program with several subprograms. All of the logic and computations for the inducer, inducer turbine, pump, and main turbine are handled in the Main Program. The subprograms are used for procedures such as input, output, table interpolations, and hydrogen properties. The following is a complete list of these programs as well as their function:

MAIN	-	All logic and computations related to the inducer, pump, and turbines.
FILE	-	Used to read-in hydrogen properties deck.
INTAB	-	Used to read-in and list tabulated data representing the turbopump characteristic curves.
INPUT	-	Used to read-in and list case data including time-dependent input data.
SHPIN	-	Establishes the relationship between inducer power and speed.
TABIN	-	Single interpolation subroutine used to interpolate turbine curves.
TABP	-	Double interpolation subroutine used to interpolate pump and inducer curves.
HPROP	-	Used to determine supercooled liquid hydrogen properties.
SVSL	-	Used to determine saturated liquid hydrogen density.
VPFUN	-	Used to determine the vapor pressure of hydrogen.
CP	-	Hydrogen gas specific heat subprogram.
GAMMA	-	Hydrogen gas specific heat ratio subprogram.
PRATO	-	Used to "initialize" main turbine pressure ratio.
INLET	-	Suction line waterhammer solution
DIAG	-	Subprogram used to write diagnostic messages.
OUT1	-	Principal output subprogram used to list complete set of computed data at specified computation intervals.
OUT2	-	Secondary output subprogram used to list inducer and suction parameters at intermediate computation intervals.
PLOT	-	Dummy subprogram to be replaced by an appropriate plotting set-up program if desired.

The details of each of these programs, including flow charts, are presented in the following discussions. The computer program listing is included as Appendix A.

1. Main Program

Suction line sonic velocity (Subprogram HPROP)

$$a = f(P_{I,i},\ T_{I,i})$$

Computation time interval

$$\Delta t = L_{sL}/a \qquad \text{Eq. (5)}$$

Suction line loss coefficient

$$C_{sL} = \frac{(f)\ (L_S)}{2\ g\ D} \qquad \text{Eq. (6)}$$

Time dependent input conditions,

Tank pressure (Subprogram TABIN)

$$P_{Tk} = f(\text{Time})$$

Main turbine inlet temperature (Subprogram TABIN)

$$T'_{mT,i} = f(\text{Time})$$

Main turbine inlet total pressure (Subprogram TABIN)

$$P'_{mT,i} = f(\text{Time})$$ (Program option 1)

Main shaft speed (Subprogram TABIN)

$$N_m = f(\text{Time})$$

Main turbine gas properties,

Specific heat ratio (Subprogram GAMMA)

$$\gamma_{mT} = f(T'_{mT,i},\ P'_{mT,i})$$

Specific heat (Subprogram CP)

$$C_{p,mT} = f(T'_{mT,i},\ P'_{mT,i})$$

Inducer inlet vapor pressure

$$PVP_{I,i} = f(T_{I,i})$$ (Subprogram VPFUN)

Inducer inlet specific volume

If $P_{I,i} \leq PVP_{I,i}$ (Use saturation densi

$$SV_{I,i} = f(T_{I,I})$$ (Subprogram SVSL)

If $P_{I,i} > PVP_{I,i}$

$$SV_{I,i} = f(P_{I,i},\ T_{I,i})$$ (Subprogram HPROP)

Pump inlet flow rate

$$Q_{p,i} = (Q/N)_p \, N_p \qquad \text{Eq. (7)}$$

Pump inlet vapor pressure

$$PVP_{p,i} = f(T_{p,i}) \qquad \text{(Subprogram VPFUN)}$$

Pump inlet specific volume

$$\text{If } P_{p,i} \leq PVP_{p,i} \qquad \text{(Use saturation density)}$$

$$SV_{p,i} = f(T_{p,i}) \qquad \text{(Subprogram SVSL)}$$

$$\text{If } P_{p,i} > PVP_{p,i}$$

$$SV_{p,i} = f(P_{p,i}, T_{p,i}) \qquad \text{(Subprogram HPROP)}$$

Pump weight flow rate

$$\dot{W}_p = \frac{Q_{p,i}}{(SV_{p,i})\,(60)\,(7.4806)} \qquad \text{Eq. (8)}$$

$$\dot{W}_I = \dot{W}_p$$

Inducer inlet pressure

$$P_{I,i} = f(\Delta t, \dot{W}_I, a, SV_{I,i}) \qquad \text{(Subprogram INLET)}$$

Inducer volumetric flow rate

$$Q_{I,i} = (SV_{I,i})\,(60)\,(7.4806)\,(\dot{W}_I) \qquad \text{Eq. (9)}$$

Inducer inlet total pressure

$$P'_{I,i} = P_{I,i} + \left(\frac{\dot{W}}{A_i}\right)^2_I \frac{144\, SV_{I,i}}{2\, g} \qquad \text{Eq. (10)}$$

Inducer net positive suction pressure

$$NPSP_I = P'_{I,i} - PVP_{I,i} \qquad \text{Eq. (11)}$$

Inducer net positive suction head

$$NPSH_I = (144)\ (NPSP_I)\ (SV_{I,i}) \qquad \text{Eq. (12)}$$

Inducer normalized suction conditions

$$\left(\frac{NPSH}{N^2}\right)_I = \frac{NPSH_I}{N_I^{\,2}} \qquad \text{Eq. (13)}$$

Inducer normalized flow rate

$$(Q/N)_I = \frac{Q_{I,i}}{N_I} \qquad \text{Eq. (14)}$$

Inducer normalized head rise

$$\left(\frac{\Delta H}{N^2}\right)_I = f\left[\left(\frac{NPSH}{N^2}\right)_I,\ (Q/N)_I\right] \qquad \text{(Subprogram TABP)}$$

Inducer efficiency

$$\eta_I = f\left[\left(\frac{NPSH}{N^2}\right)_I,\ (Q/N)_I\right] \qquad \text{(Subprogram TABP)}$$

Inducer head rise

$$\Delta H_I = \left(\frac{\Delta H}{N^2}\right)_I N_I^{\,2} \qquad \text{Eq. (15)}$$

Inducer total pressure rise

$$\Delta P'_I = \frac{\Delta H_I}{144\ SV_{I,i}} \qquad \text{Eq. (16)}$$

Inducer power

$$SHP_I = \frac{\dot{W}_I\ \Delta H_I}{550\ \eta_I} \qquad \text{Eq. (17)}$$

Inducer torque

$$\tau_I = \frac{33000\ SHP_I}{2\pi\ N_I} \qquad \text{Eq. (18)}$$

Inducer discharge total pressure

$$P'_{I,e} = P'_{I,i} + \Delta P'_I \qquad \text{Eq. (19)}$$

Pump inlet total pressure

$$P'_{p,i} = P'_{I,e} \qquad \text{Eq. (20)}$$

Pump inlet static pressure

$$P_{p,i} = P'_{p,i} - \left(\frac{\dot{W}}{A_i}\right)^2_p \frac{144\ SV_{p,i}}{2\ g} \qquad \text{Eq. (21)}$$

Inducer discharge pressure

$$P_{I,e} = P_{p,i} \qquad \text{Eq. (22)}$$

Pump net positive suction pressure

$$NPSP_p = P'_{p,i} - PVP_{p,i} \qquad \text{Eq. (23)}$$

Pump net positive suction head

$$NPSH_p = (144)\ (NPSP_p)\ (SV_{p,i}) \qquad \text{Eq. (24)}$$

Pump normalized suction conditions

$$\left(\frac{NPSH}{N^2}\right)_p = \frac{NPSH_p}{N_p^{\ 2}} \qquad \text{Eq. (25)}$$

Pump normalized head rise

$$\left(\frac{\Delta H}{N^2}\right)_p = f\left[\left(\frac{NPSH}{N^2}\right)_p,\ (Q/N)_p\right] \qquad \text{(Subprogram TABP)}$$

Pump efficiency

$$\eta_p = f\left[\left(\frac{NPSH}{N^2}\right)_p,\ (Q/N)_p\right] \qquad \text{(Subprogram TABP)}$$

Pump head rise

$$\Delta H_p = \left(\frac{\Delta H}{N^2}\right)_p N_p^{\,2} \qquad \text{Eq. (26)}$$

Pump total pressure rise

$$\Delta P'_p = \frac{\Delta H_p}{144\ SV_{p,i}} \qquad \text{Eq. (27)}$$

Pump power

$$SHP_p = \frac{\dot{W}_p\ \Delta H_p}{550\ \eta_p} \qquad \text{Eq. (28)}$$

Pump torque

$$\tau_p = \frac{33000\ SHP_p}{2\pi\ N_m} \qquad \text{Eq. (29)}$$

Pump discharge total pressure

$$P'_{p,e} = P'_{p,i} + \Delta P'_p \qquad \text{Eq. (30)}$$

Pump discharge static pressure

$$P_{p,e} = P'_{p,e} - \left(\frac{\dot{W}}{A_e}\right)_p^2 \frac{144\ SV_{p,i}}{2\ g} \qquad \text{Eq. (31)}$$

Main turbine flow parameter

$$FP_{m,T} = \frac{\dot{W}_{mT}\sqrt{T'_{mT,i}}}{P'_{mT,i}} = f(Pr_{mT}) \qquad \text{(Subprogram TABIN)}$$

Main turbine isentropic spouting velocity

$$Co'_{mT} = \sqrt{2\ g\ J\ C_{p,mT}\ T'_{mT,i}\left[1 - \left(\frac{1}{Pr'_{mT}}\right)^{\frac{\gamma_{mT}-1}{\gamma_{mT}}}\right]}$$

Eq. (32)

Main turbine mean blade speed

$$U_{mT} = \frac{2\pi\ N_m\ r_m}{(12)\ (60)} \qquad \text{Eq. (33)}$$

Main turbine velocity ratio

$$(U/Co)_{mT} = \frac{U_{mT}}{Co'_{mT}} \qquad \text{Eq. (34)}$$

Main turbine total efficiency

$$\eta_{mT} = f\left[\left(\frac{U}{Co}\right)_{mT}\right] \qquad \text{(Subprogram TABIN)}$$

Main turbine total enthalpy drop

$$\Delta h_{mT} = \frac{\eta_{mT}\ Co'^2_{mT}}{2\ g\ J} \qquad \text{Eq. (35)}$$

Main turbine flow rate (Program option 1)

$$\dot{W}_{mT} = F\ P_{mT}\left(\frac{P'_{mT,i}}{T'_{mT,i}}\right) \qquad \text{Eq. (36)}$$

Main turbine power (Program option 1)

$$SHP_{mT} = \frac{\dot{W}_{mT}\ \Delta h_{mT}\ J}{550} \qquad \text{Eq. (37)}$$

Main turbine torque

$$\tau_{mT} = \frac{33000\ SHP_{mT}}{2\pi\ N_m} \qquad \text{Eq. (38)}$$

Main shaft acceleration relation, Program option 1.

$$N_{m,\ t\ +\ \Delta t} = N_{m,t} + \frac{720\ \Delta t}{2\pi\ I_m}\ (\tau_{mT} - \tau_p) \qquad \text{Eq. (39)}$$

Main shaft acceleration relation, Program option 2.

$$\tau_{mT,t} = \tau_{p,t} + \frac{2\pi\ I_m}{720\ \Delta t}\ [N_{m,t} - N_{m,(t\ -\ \Delta t)}] \qquad \text{Eq. (40)}$$

Main turbine power (Program option 2)

$$SHP_{mT} = \frac{2\pi\ N_m\ \tau_{mT}}{33000} \qquad \text{Eq. (41)}$$

Main turbine flow rate (Program option 2)

$$\dot{W}_{mT} = \frac{550\ SHP_{mT}}{J\ \Delta h_{mT}} \qquad \text{Eq. (42)}$$

Main turbine inlet total pressure (Program option 2)

$$P'_{mT,i} = \frac{\dot{W}_{mT} \sqrt{T'_{mT,i}}}{F\ P_{mT}} \qquad \text{Eq. (43)}$$

Main turbine discharge total pressure

$$P'_{mT,e} = P'_{mT,i}/Pr'_{mT} \qquad \text{Eq. (44)}$$

Inducer inlet total pressure

$$P'_{IT,i} = P'_{mT,e} \qquad \text{Eq. (45)}$$

Inducer turbine discharge static pressure

An incompressible treatment of the turbine exhaust system losses results in the Darcey equation for head loss

$$H_{Loss} = \frac{KV^2}{2\ g}$$

From continuity

$$\dot{W} = \rho VA$$

then

$$H_{Loss} = \frac{K\ \dot{W}^2}{2\ g\ \rho^2\ A^2}$$

and

$$\Delta P = \frac{\rho\ H_{Loss}}{144} = \frac{\dot{W}^2}{2\ g\ 144\ \rho A^2}$$

Using the ideal gas equation of state to compute exhaust inlet density

$$\rho = \frac{P_{IT,e}}{R\ T_{IT,e}}$$

then

$$\Delta P = \frac{K\ \dot{W}^2\ R\ T_{IT,e}}{2\ g\ 144\ P_{IT,e}\ A^2}$$

Let

$$C_{ex} = \frac{K\ R}{2\ g\ 144\ A^2} = \text{constant for a particular exhaust system}$$

then

$$\Delta P = \frac{C_{ex}\ \dot{W}^2_{IT}\ T_{IT,e}}{P_{IT,e}} = P_{IT,e} - P_{ex}$$

Solving for inducer turbine exhaust pressure ($P_{IT,e}$) in terms of exhaust system backpressure (P_{ex}), turbine flow rate ($\dot{W}_{IT}$), turbine exhaust temperature ($T_{IT,e}$), and exhaust system loss coefficient (C_{ex}), the resulting relationship is

$$P_{IT,e} = \frac{P_{ex} + \sqrt{P_{ex}^{\ 2} + 4\ C_{ex}\ \dot{W}^2_{IT}\ T_{IT,e}}}{2} \qquad \text{Eq. (46)}$$

Inducer turbine total to static pressure ratio

$$Pr_I = P'_{IT,i}/P_{IT,e} \qquad \text{Eq. (47)}$$

Inducer turbine flow parameter

$$FP_I = \frac{\dot{W}_{IT}\sqrt{T'_{IT,i}}}{P'_{IT,i}} = f(Pr_{IT}) \qquad \text{(Subprogram TABIN)}$$

Main turbine exhaust total temperature

$$T'_{mT,e} = T'_{mT,i} - \frac{\Delta h_{mT}}{C_{p,mT}} \qquad \text{Eq. (48)}$$

Inducer turbine inlet total temperature

$$T'_{IT,i} = T'_{mT,e} \qquad \text{Eq. (49)}$$

Inducer turbine flow rate

$$\dot{W}_{IT} = \frac{F\ P_{IT}\ P'_{IT,i}}{\sqrt{T'_{IT,i}}} \qquad \text{Eq. (50)}$$

The pressure ratio split between turbines must eventually be such that the main turbine and the inducer turbine flow rates are equal (within a tolerance). The main turbine pressure ratio iteration is carried out as indicated on Figure No. 109. The following equations are involved.

On a finite difference basis, the rate of change of main turbine flow rate with main turbine pressure ratio is

$$\frac{\Delta \dot{W}_{mT}}{\Delta Pr_{mT}} = \frac{\dot{W}_{mT}\ (n) - \dot{W}_{mT}\ (n-1)}{Pr_{mT}\ (n) - Pr_{mT}\ (n-1)} \qquad \text{Eq. (51)}$$

and the rate of change of inducer turbine flow rate with main turbine pressure ratio is

$$\frac{\Delta \dot{W}_{IT}}{\Delta Pr_{IT}} = \frac{\dot{W}_{IT}\ (n) - \dot{W}_{IT}\ (n-1)}{Pr_{mT}\ (n) - Pr_{mT}\ (n-1)} \qquad \text{Eq. (52)}$$

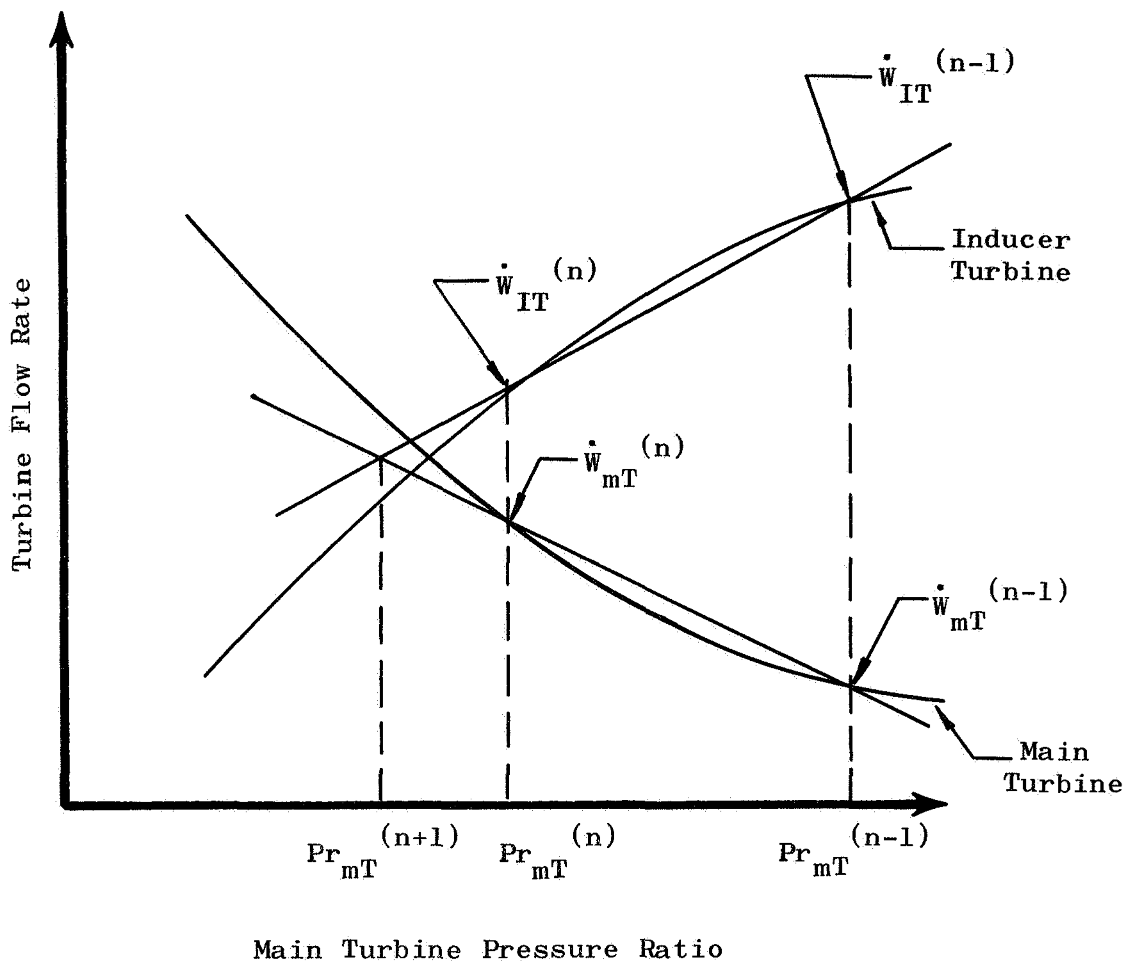
Using these two slopes, a new pressure ratio estimate can be made (see Figure No. 109) from the relationship

$$Pr_{mT}\ (n+1) = Pr_{mT}\ (n) + \frac{\dot{W}_{IT}\ (n) - \dot{W}_{mT}\ (n)}{\dfrac{\Delta \dot{W}_{mT}}{\Delta Pr_{mT}} - \dfrac{\Delta \dot{W}_{IT}}{\Delta Pr_{mT}}} \qquad \text{Ea. (53)}$$

Inducer turbine gas properties

Specific heat ratio

$$\gamma_{IT} = f(T'_{IT,i},\ P'_{IT,i}) \qquad \text{(Subprogram GAMMA)}$$



Note: The slopes of the curves are for the case of constant main turbine power

Figure 109. Main Turbine Pressure Ratio

Specific heat

$$C_{p,IT} = f(T'_{IT,i}, P'_{IT,i}) \qquad \text{(Subprogram CP)}$$

Inducer turbine ideal enthalpy change

$$\Delta h_{IT,id} = C_{p,IT} \, T'_{IT,i} \left[1 - \left(\frac{1}{Pr_{IT}} \right)^{\frac{\gamma_{IT}-1}{\gamma_{IT}}} \right] \qquad \text{Eq. (54)}$$

Inducer isentropic spouting velocity

$$Co_{IT} = \sqrt{2 \; g \; J \; \Delta h_{IT,id}} \qquad \text{Eq. (55)}$$

Inducer turbine mean blade velocity

$$U_{IT} = \frac{2\pi \; N_i \; r_I}{(12) \; (60)} \qquad \text{Eq. (56)}$$

Inducer turbine velocity ratio

$$(U/Co)_{IT} = \frac{U_{IT}}{Co_{IT}} \qquad \text{Eq. (57)}$$

Inducer turbine static efficiency

$$\eta_{IT} = f[(U/Co)_{IT}] \qquad \text{(Subprogram TABIN)}$$

Inducer turbine enthalpy change

$$\Delta h_{IT} = \eta_{IT} \, \Delta h_{IT,id} \qquad \text{Eq. (58)}$$

Inducer turbine exhaust total temperature

$$T'_{IT,e} = T'_{IT,i} - \frac{\Delta h_{IT}}{C_{p,IT}} \qquad \text{Eq. (59)}$$

Inducer turbine power

$$SHP_{IT} = \frac{\dot{W}_{IT} \, \Delta h_{IT} \, J}{550} \qquad \text{Eq. (60)}$$

Inducer turbine torque

$$\tau_{IT} = \frac{33000\ SHP_{IT}}{2\pi\ N_I} \qquad \text{Eq. (61)}$$

Inducer speed corrections are made using a technique similar to that discussed previously for main turbine pressure ratio corrections. This leads to the following expression for successive inducer speed iterations:

$$N_I\ (n+1) = N_I\ (n) + \frac{SHP_{IT}\ (n) - SHP_I\ (n)}{\frac{\Delta SHP_I}{\Delta N_I} - \frac{\Delta SHP_{IT}}{\Delta N_I}} \qquad \text{Eq. (62)}$$

Inducer turbine acceleration relationship

$$N_{I,t\ +\ \Delta t} = N_{I,t} + \frac{720\ \Delta t}{2\pi\ I_I}\ (\tau_{IT} - \tau_I) \qquad \text{Eq. (63)}$$

The Main Program computational sequence is illustrated on Figure No. 110.

2. Subprograms

a. FILE

All of the hydrogen properties deck listing (Appendix B) is read-in by the subprogram FILE. These data are stored in tabular form for use in the hydrogen properties subprograms. Figure No. 111 is a flow chart of this subprogram.

b. INTAB

The tabular data representing the turbopump component characteristic curves are read-in and stored in appropriate arrays for use in the interpolation subprograms. Cards 1 through 25, which are subsequently described in Section VII,D, are the cards read in this program. Figure No. 112 is a flow chart of this subprogram.

c. INPUT

The data pertinent to a particular case (Cards 26 through 36; see Section VII,D) are read-in by the subprogram INPUT. Figure No. 113 is a flow chart of this subprogram.

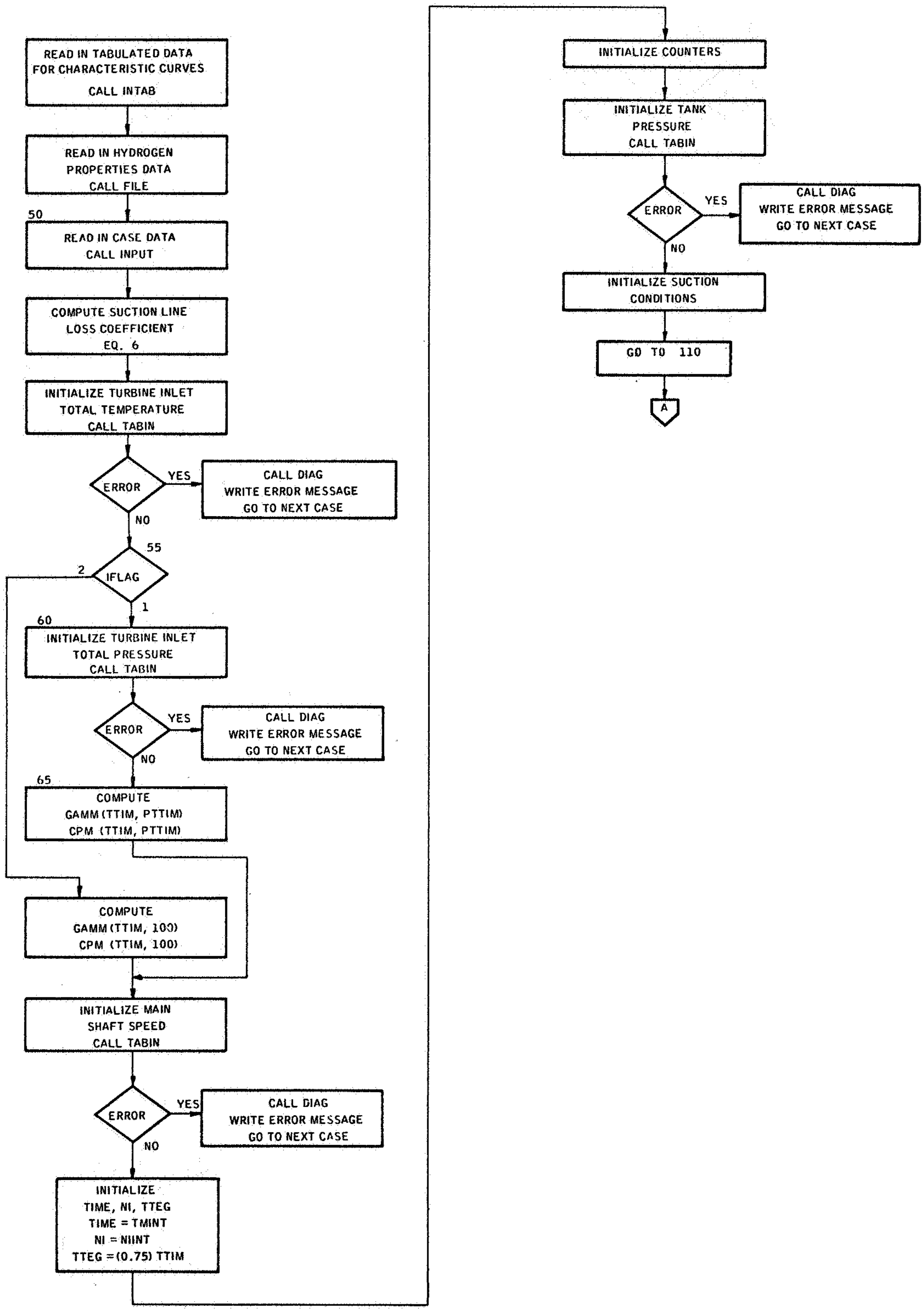


Figure 110. - Main Program Computational Sequence.
(Sheet 1 of 7)

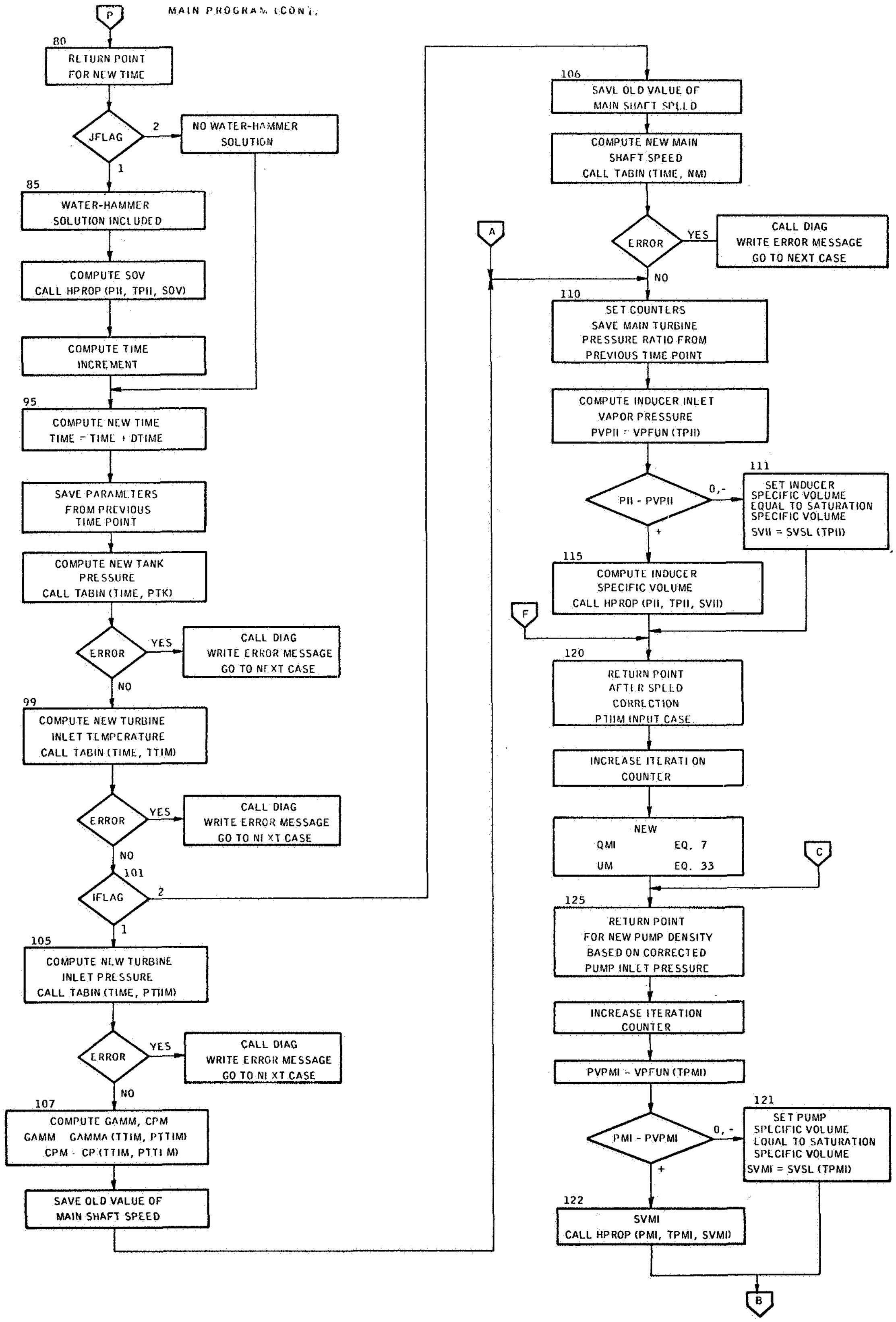


Figure 110. - Main Program Computational Sequence.
(Sheet 2 of 7)

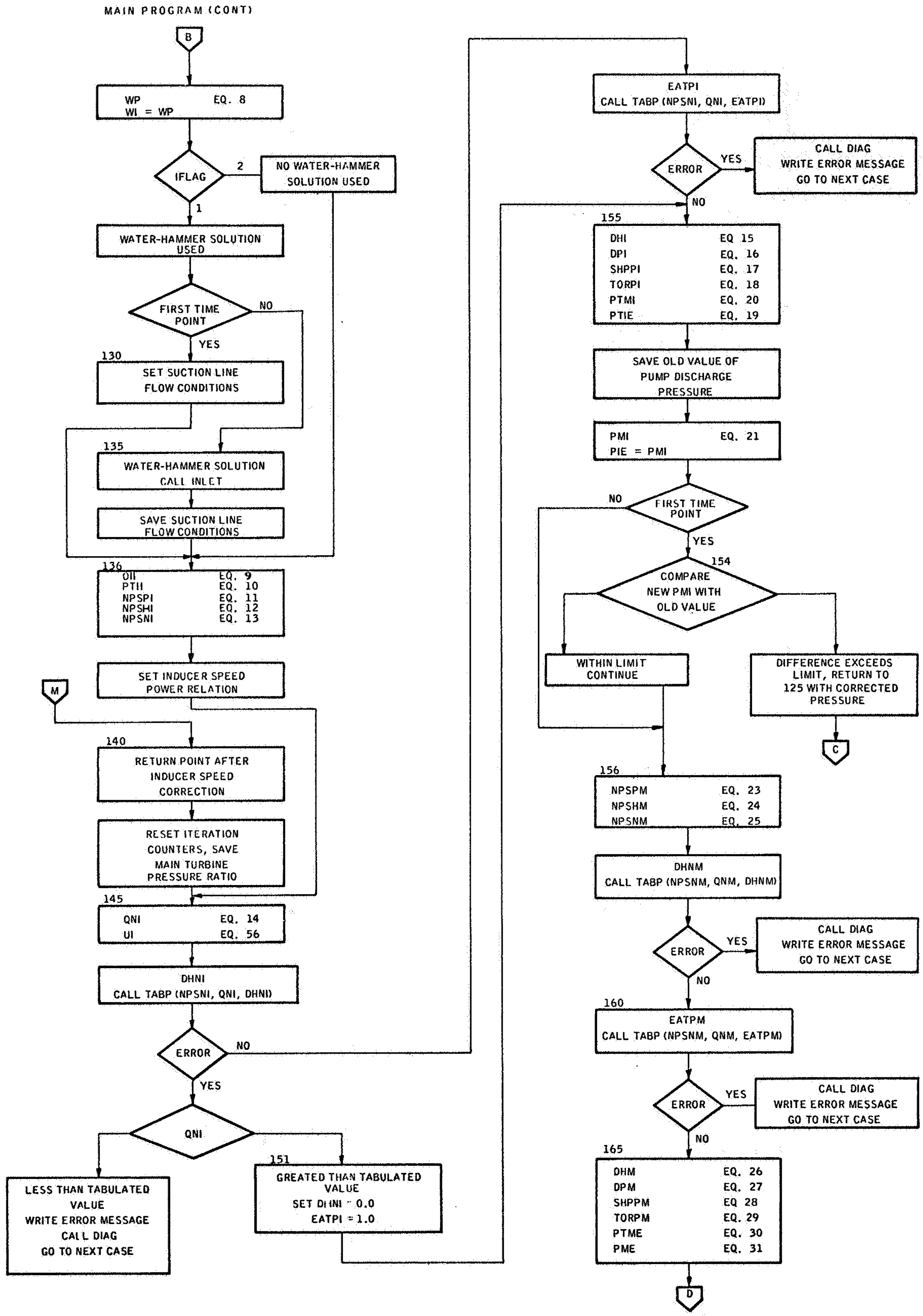


Figure 110. - Main Program Computational Sequence. (Sheet 3 of 7)

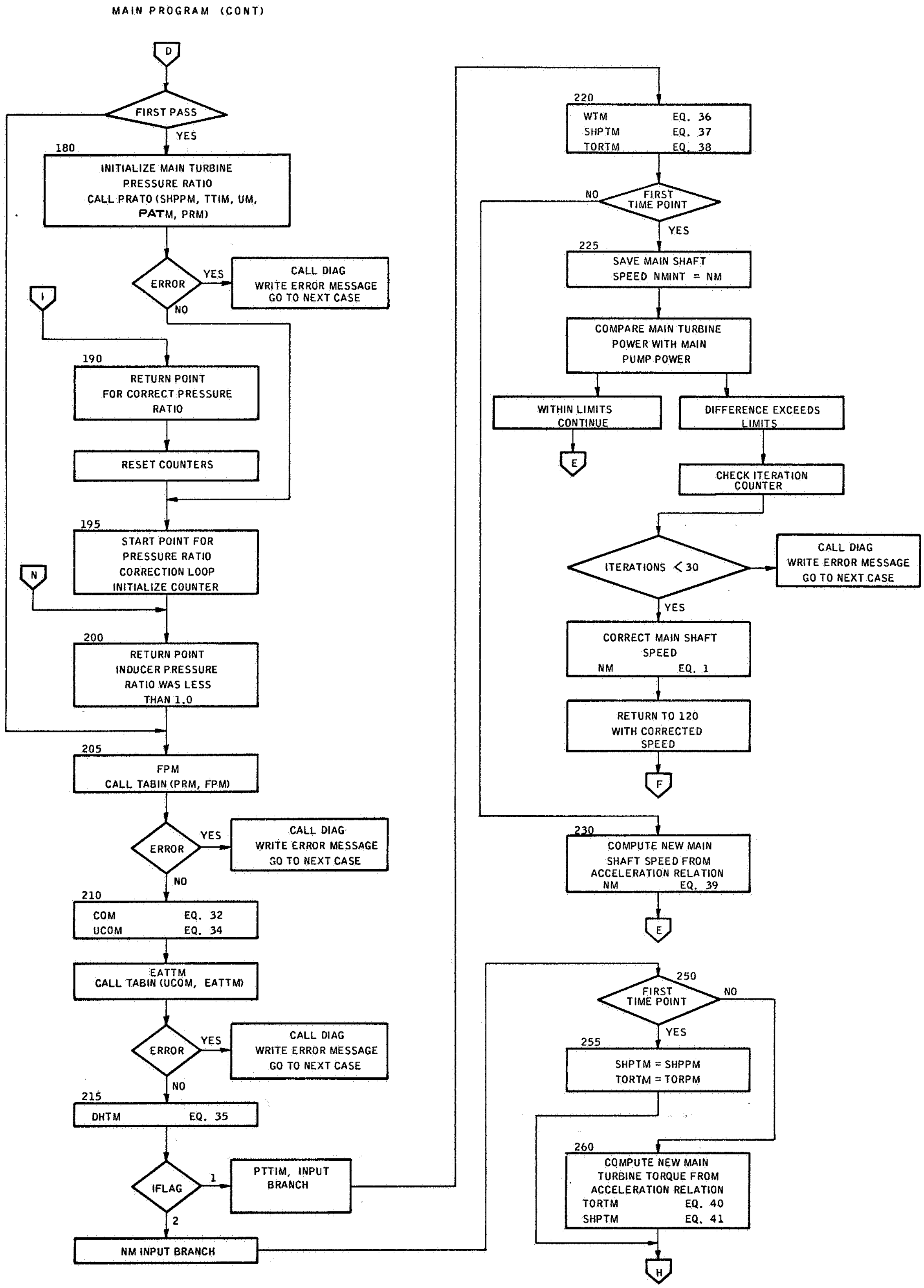


Figure 110. Main Program Computational Sequence (Sheet 4 of 7)

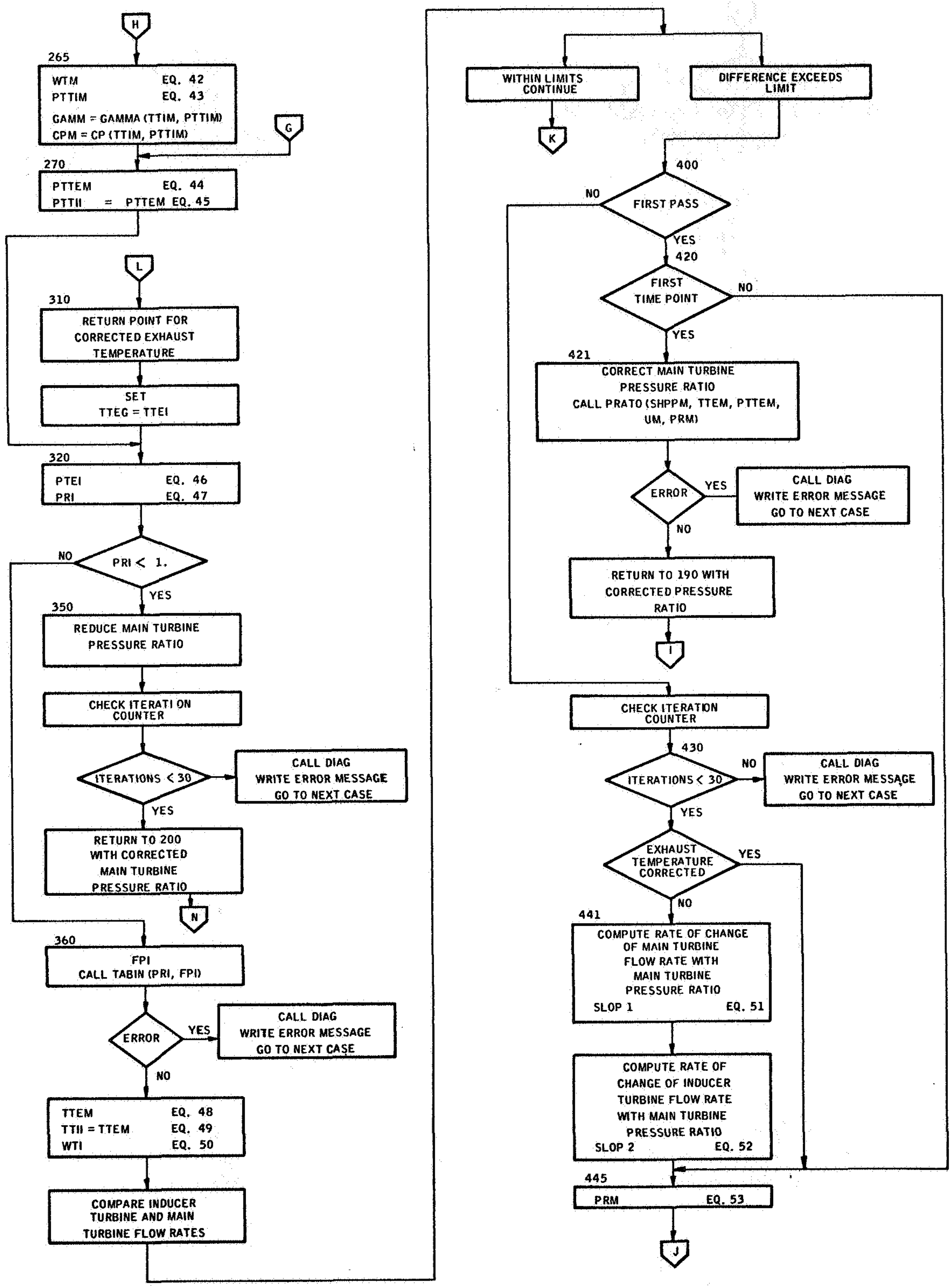


Figure 110. - Main Program Computational Sequence. (Sheet 5 of 7)

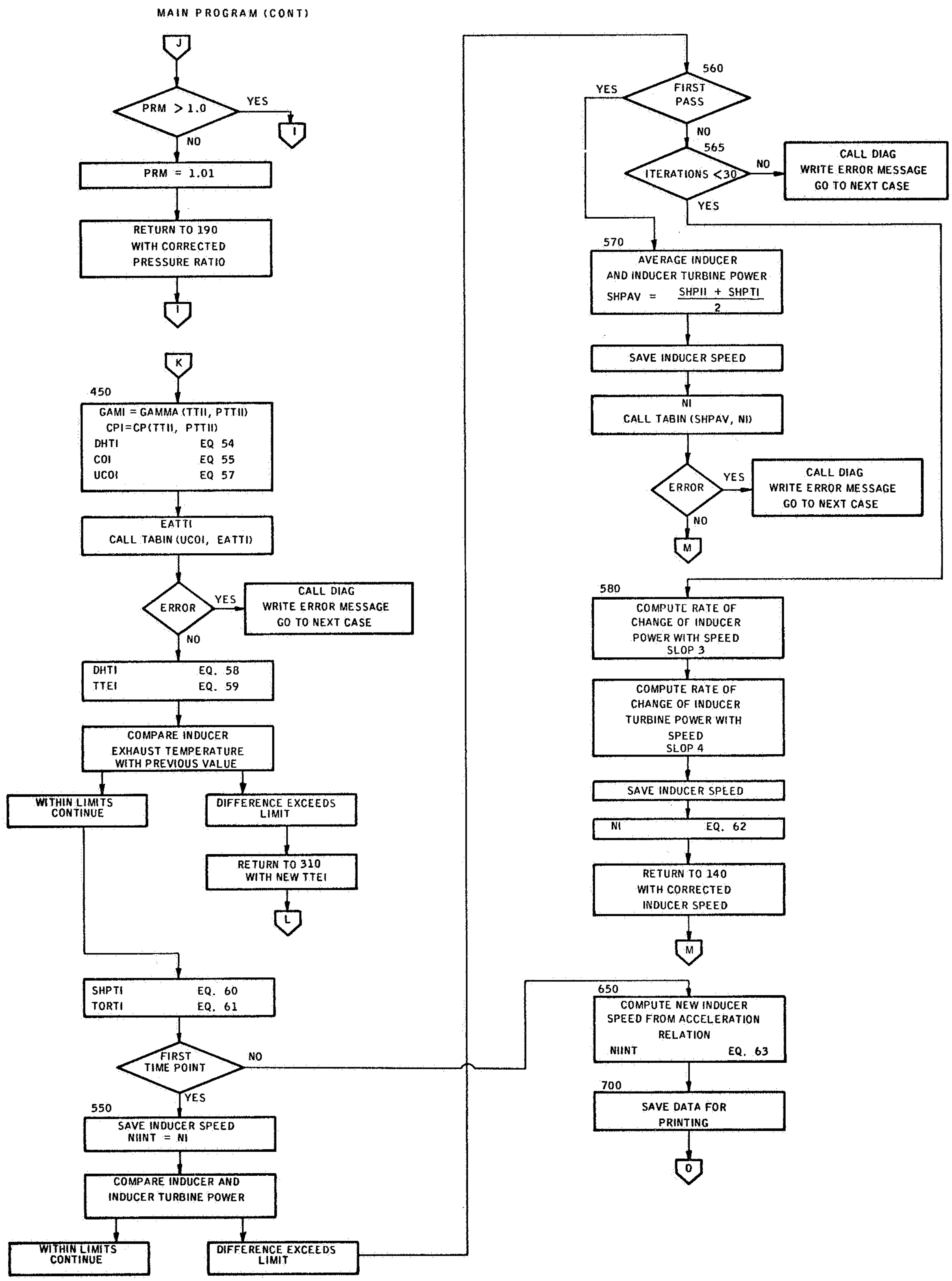


Figure 110. - Main Program Computational Sequence.
(Sheet 6 of 7)

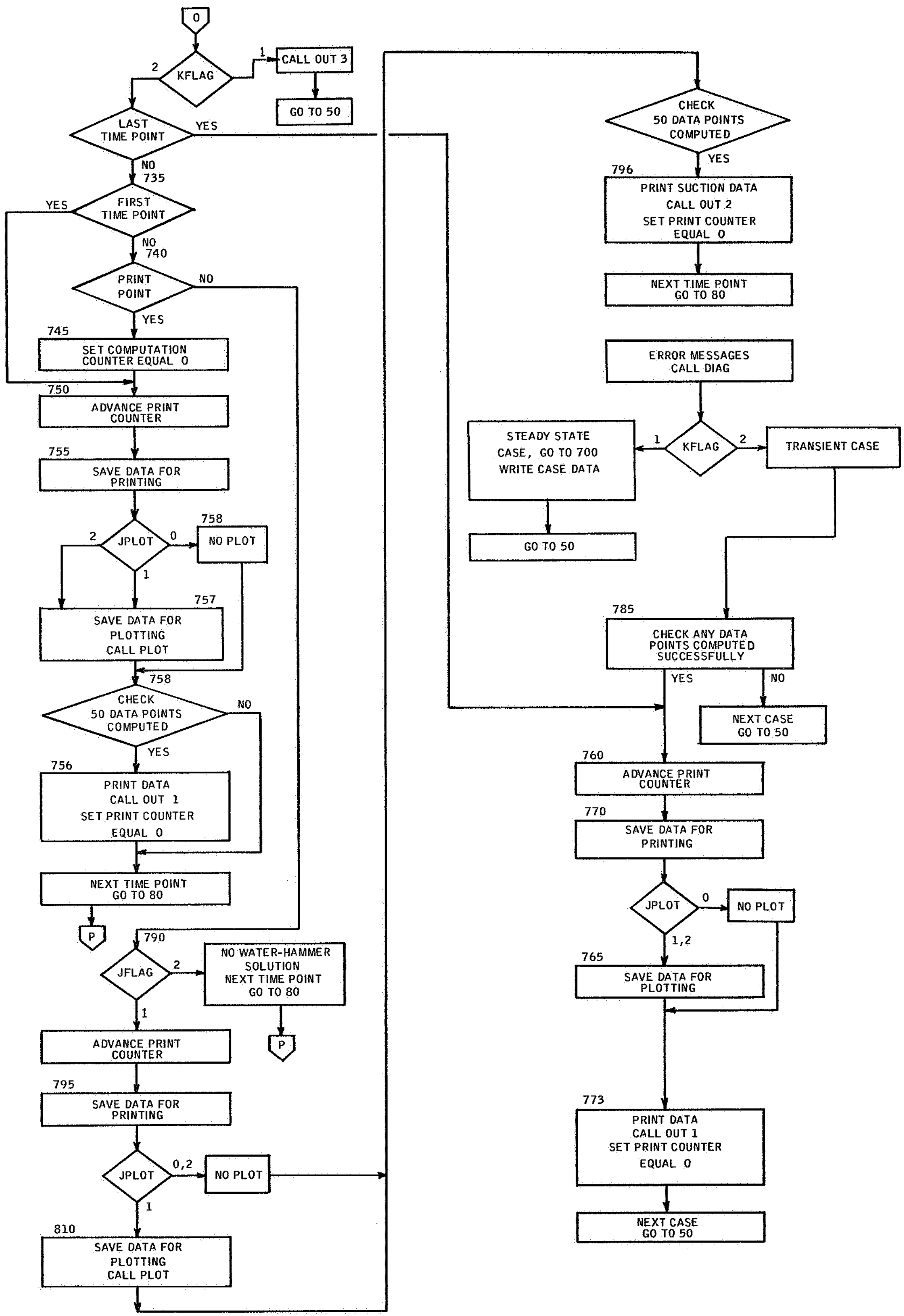


Figure 110. Main Program Computational Sequence (Sheet 7 of 7)

SUBROUTINE FILE

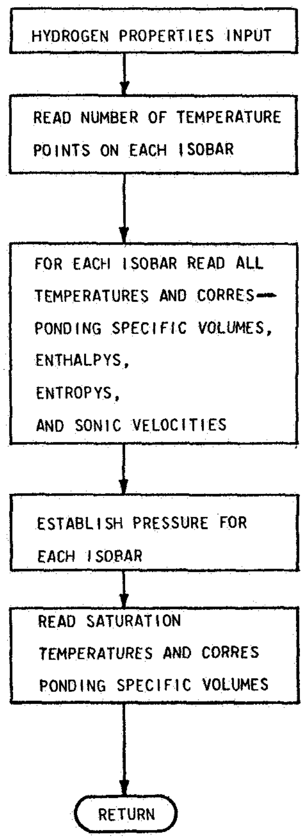


Figure 111. - Subroutine FILE Flow Chart.

SUBROUTINE INTAB

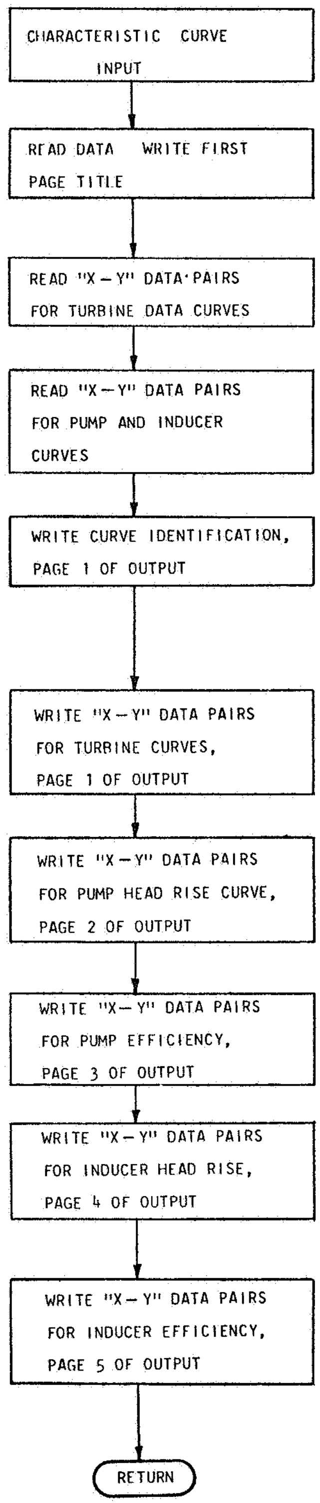


Figure 112. - Subroutine INTAB Flow Chart.

SUBROUTINE INPUT

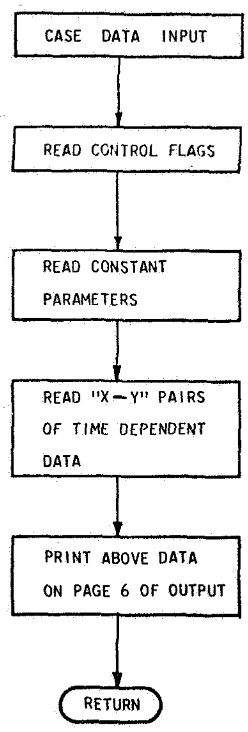


Figure 113. - Subroutine INPUT Flow Chart.

d. SHPIN

This subprogram is used to establish a relationship between inducer speed and shaft power for given values of inducer normalized suction head ($NPSH/N^2$) and inducer flow rate. The speed-power relationship is used in the inducer speed iteration loop of the main program.

This relationship is established using the tabulated characteristic data for the inducer. Corresponding values of $\Delta H/N^2$, η, and Q/N were input for curves of constant $NPSH/N^2$. For each tabulated value of Q/N, $\Delta H/N^2$ and η are interpolated between curves of constant $NPSH/N^2$; then, speed is computed for these points from the relationship

$$N = \frac{Q}{(Q/N)} \qquad \text{(For all Q/N) Eq. (64)}$$

and power is determined from

$$SHP = \frac{\dot{W}_p \left(\frac{\Delta H}{N^2}\right)}{550\ \eta} N^2 \qquad \text{(For all Q/N) Eq. (65)}$$

These corresponding speed and power points then are stored as elements of an array for future use (see Figure No. 114). For values of $NPSH/N^2$ which are either greater or less than the tabulated values, the maximum or minimum curve is used, respectively.

Interpolation equations used in this subprogram are as follows:

$$(\Delta H/N^2)_j = Y(1,J) + \frac{[DH - Z(I-1)]}{[Z(I) - Z(I-1)]} [Y(2,J) - Y(1,J)] \qquad \text{Eq. (66)}$$

$$(\eta)_j = S(1,J) + \frac{[DH - Z(I-1)]}{[Z(I) - Z(I-1)]} [Y(2,J) - Y(1,J)] \qquad \text{Eq. (67)}$$

Figure No. 115 is a flow chart of this subprogram.

e. TABIN

Single linear interpolation of the turbine characteristic curves and the tabular data relating inducer power to speed result from the use of this subprogram. The tabulated data are used to determine the corresponding respective dependent variable (i.e., flow parameter, FP; efficiency, η; and inducer speed) for an independent parameter (i.e., pressure ratio, Pr; velocity ratio, U/Co; or inducer shaft power, SHP_I). Figure No. 116 is a flow chart of this subprogram.

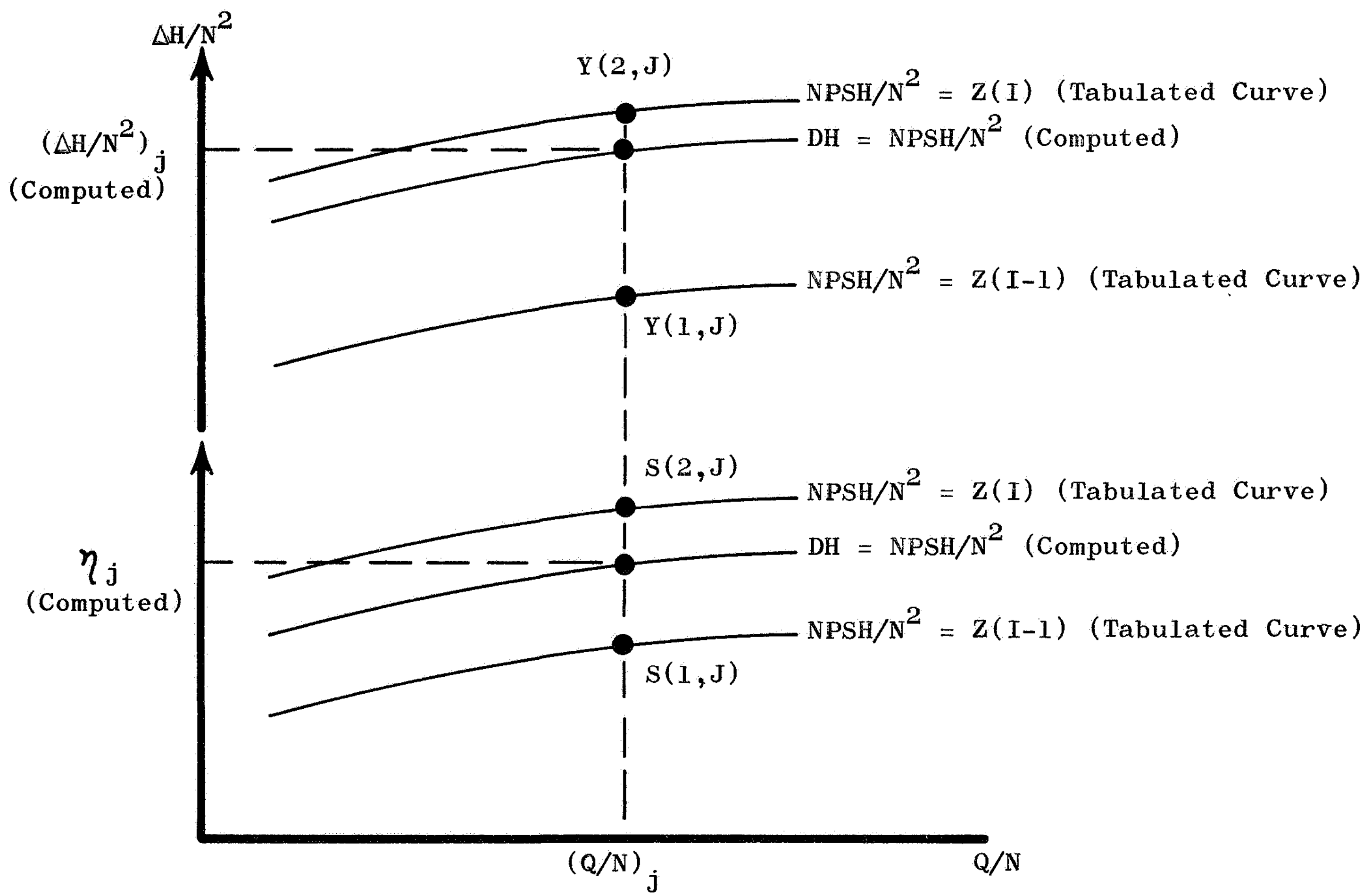


Figure 114. - SHPIN Interpolation Procedure.

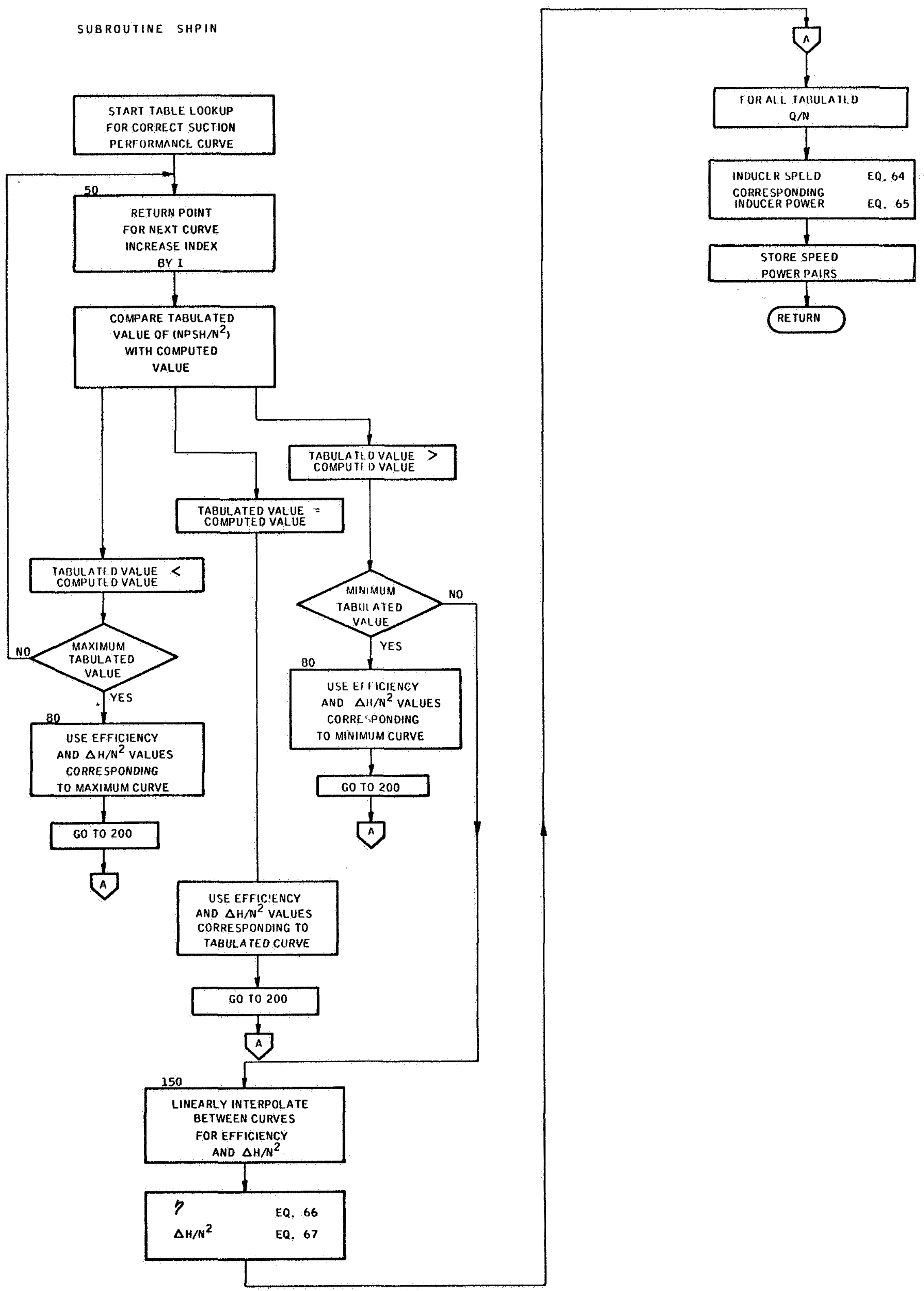


Figure 115. - Subroutine SHPIN Flow Chart.

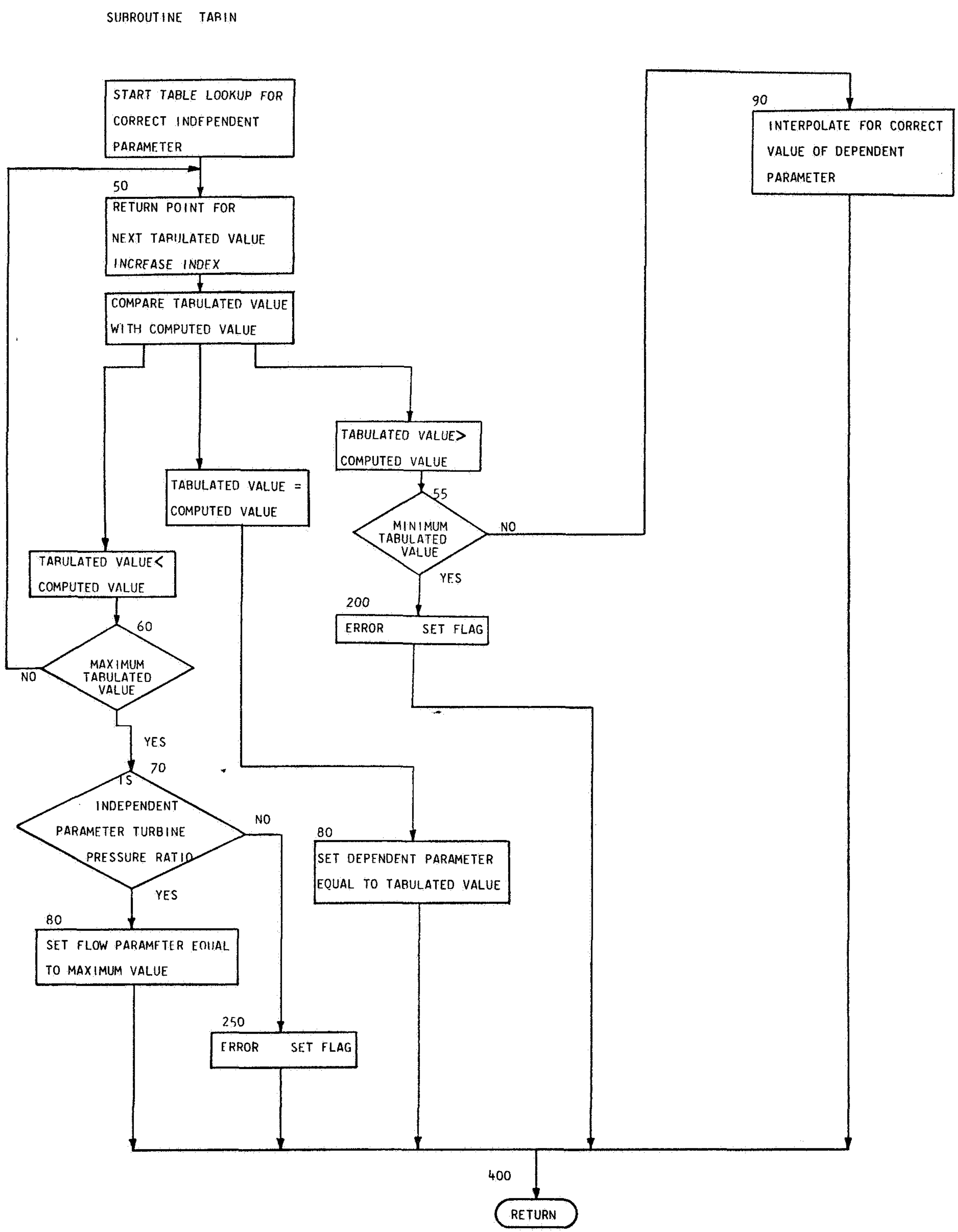


Figure 116. - Subroutine TABIN Flow Chart.

f. TABP

This is a double interpolation subprogram used to determine the pump normalized head rise ($\Delta H/N^2$), inducer normalized head rise, pump efficiency, and inducer efficiency in terms of their respective normalized flows (Q/N) and normalized suction heads ($NPSH/N^2$). Tabular data based upon the pump and inducer characteristic curves are input and stored in files by subprogram TABIN. The dependent variables, normalized head rise ($\Delta H/N^2$) and and efficiency (η), are tabulated with respect to two independent variables, Q/N and $NPSH/N^2$. This is accomplished by tabulating data pairs of η versus Q/N and $\Delta H/N^2$ versus Q/N along lines of constant $NPSH/N^2$. The table is interpolated linearly both with respect to Q/N and $NPSH/N^2$ as shown on Figure No. 117.

If $NPSH/N^2$ is greater than the maximum value for which data is tabulated, the curve of maximum $NPSH/N^2$ is used; if it is less than the minimum tabulated value, the minimum curve is used. Should Q/N be less than the minimum table value, an error is detected and control is returned to the main program for a diagnostic message. If Q/N is greater than the maximum table value, a similar diagnostic message results. Figure No. 118 is a flow chart of this subprogram.

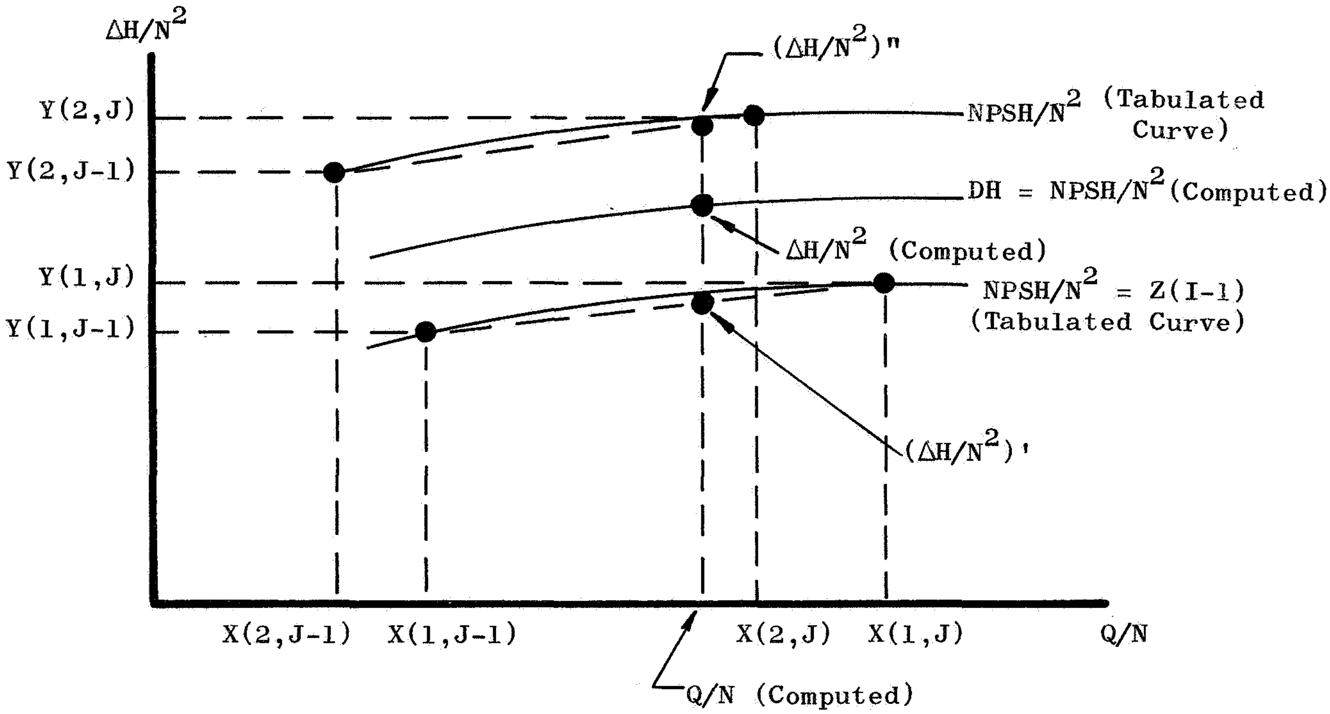
g. Hydrogen Properties Subprograms

(1) HPROP

This subprogram is used to determine properties data for liquid or supercritical hydrogen. Existing tabular hydrogen properties (Ref. 19) are utilized. The temperature range covered is from the liquid-solid phase boundary to the saturation temperature or 72°R, whichever is greater for a given isobar. The pressure range goes from one atmosphere to 100 atmospheres. The following properties are tabulated as a function of temperature for the isobars of this indicated pressure range:

- Specific Volume
- Enthalpy
- Entropy
- Sonic Velocity

These tabulated data constitute the major portion of the hydrogen properties deck listing of Appendix B. Thus, given a pressure and one of the five parameters (viz., temperature, specific volume, enthalpy, entropy, or sonic velocity), the table can be utilized to supply any one of the three remaining properties. In the Twin-Spool Program, this computer subprogram was used only to determine the specific volume and sonic velocity of the fluid as a function of pressure and temperature. Figure No. 119 is the flow chart for this subprogram.



Interpolation Equations

$$(\Delta H/N^2)' = Y(1,J-1) + \frac{[Q/N - X(1,J-1)]}{[X(1,J) - X(1,J-1)]}\left[Y(1,J) - Y(1,J-1)\right] \quad \text{Eq. (68)}$$

$$(\Delta H/N^2)'' = Y(2,J-1) + \frac{[Q/N - X(2,J-1)]}{[X(2,J) - X(2,J-1)]}\left[Y(2,J) - Y(2,J-1)\right] \quad \text{Eq. (69)}$$

$$(\Delta H/N^2) = (\Delta H/N^2)' + \frac{[NPSH/N^2 - Z(I-1)]}{[Z(I) - Z(I-1)]}\left[(\Delta H/N^2'' - (\Delta H/N^2)'\right] \quad \text{Eq. (70)}$$

The above example is for $\Delta H/N^2$; however, it also is applicable for the efficiency calculation.

Figure 117. - TABP Interpolation Procedure.

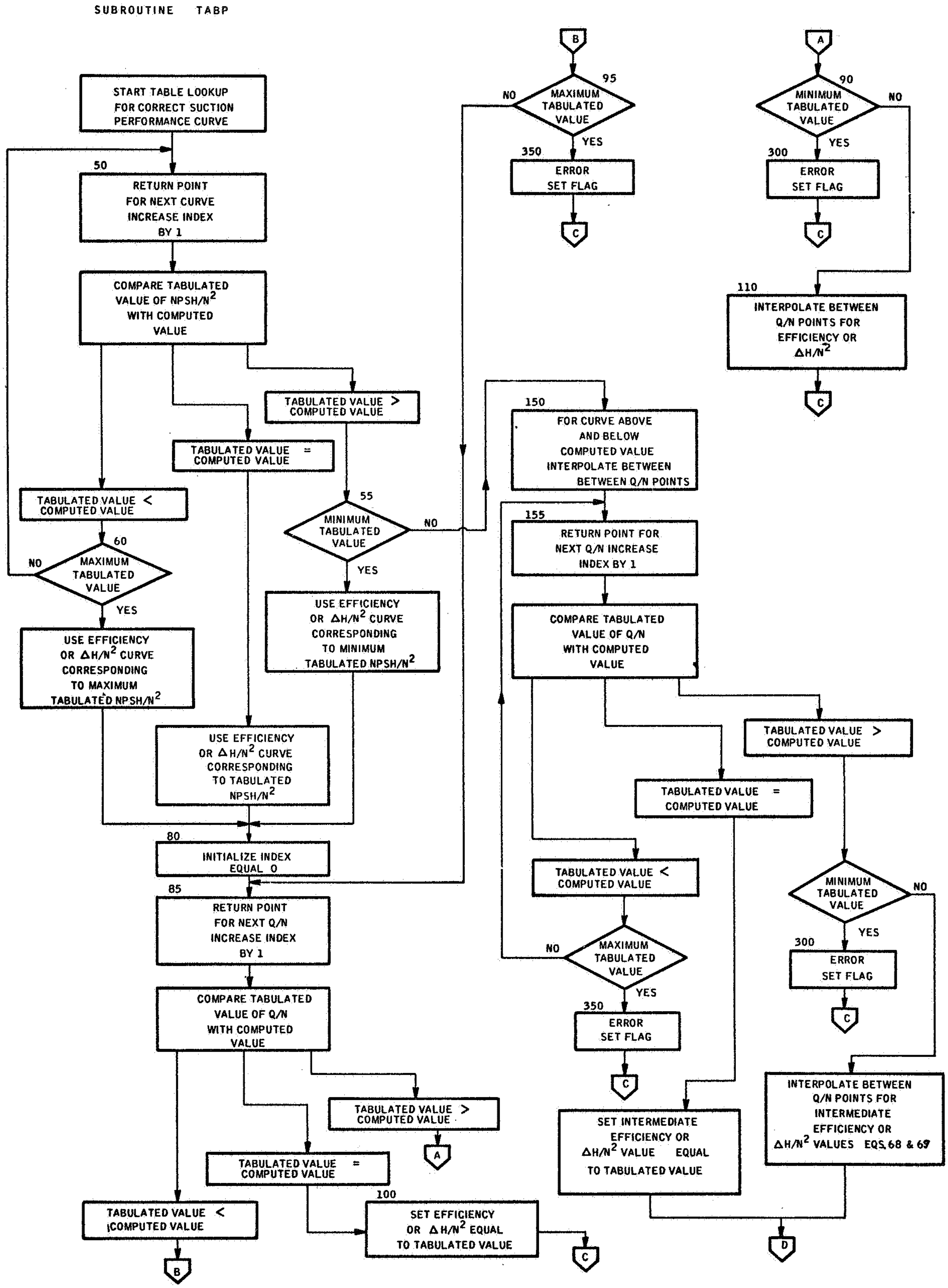


Figure 118. - Subroutine TABP Flow Chart.
(Sheet 1 of 2)

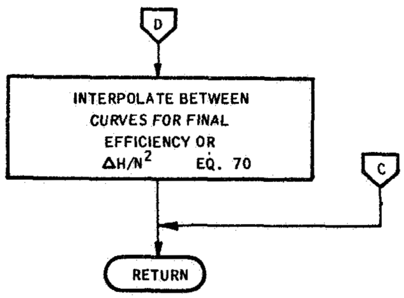


Figure 118. - Subroutine TABP Flow Chart.
(Sheet 2 of 2)

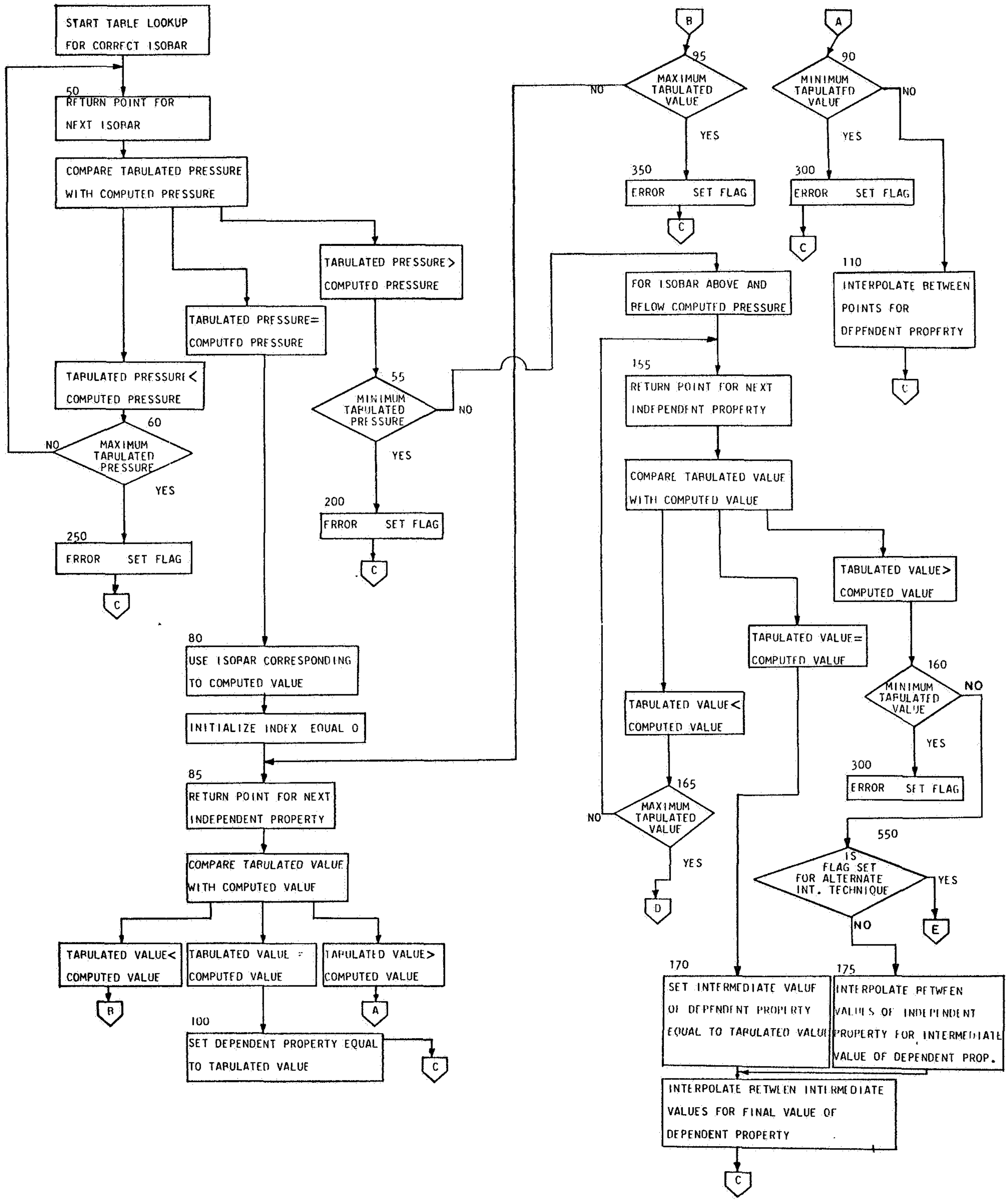


Figure 119. - Subprogram HPROP Flow Chart.
(Sheet 1 of 2)

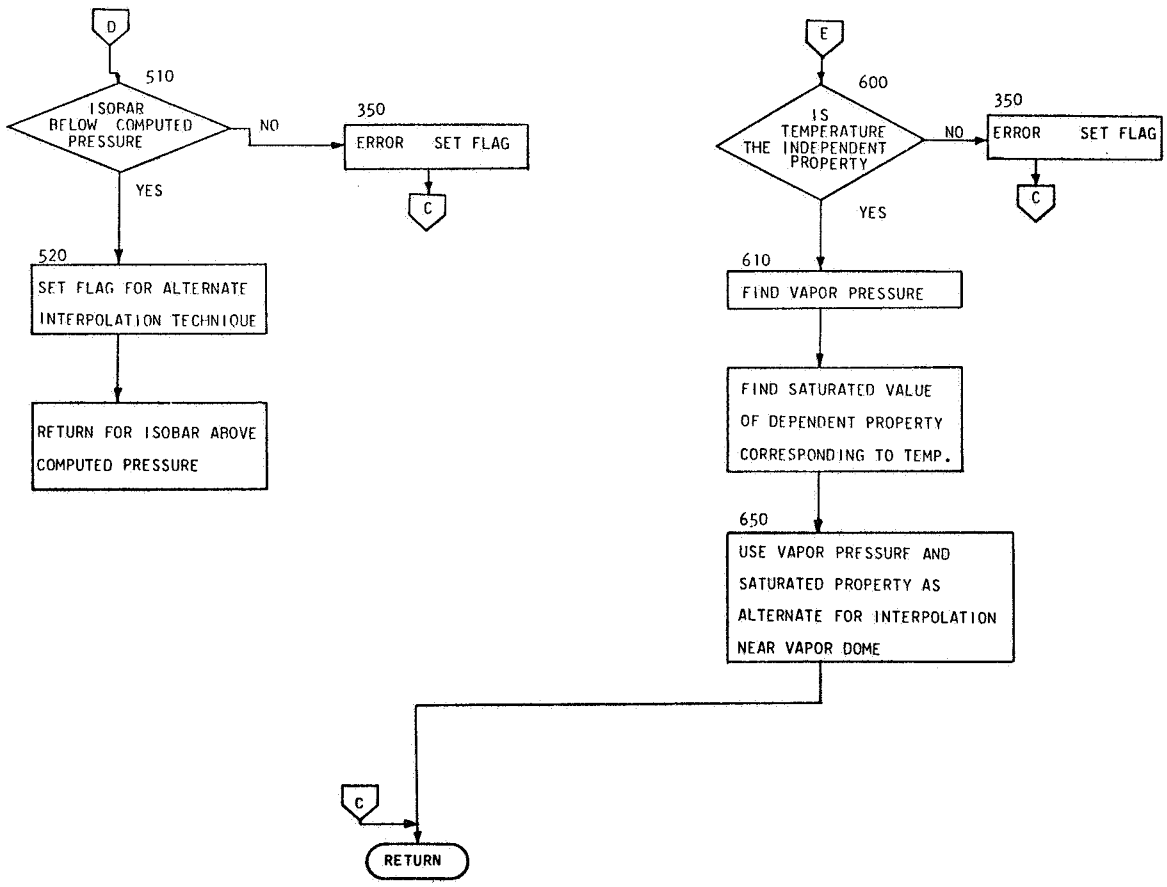


Figure 119. - Subprogram HPROP Flow Chart.
(Sheet 2 of 2)

(2) SVSL

This subprogram is used to find the specific volume of saturated liquid hydrogen, which is given by

$$SV_{sat.\ liq} = \frac{1}{\rho_{sat.\ liq}} \qquad \text{Eq. (71)}$$

where the saturated liquid density $\rho_{sat.\ liq}$ is given by the equation of state

$$\rho_{sat.\ liq.} = \rho_{crit.} + A_1 (T_{crit.}-T)^{0.38} + A_2 (T_{crit.}-T) + A_3 (T_{crit.}-T)^{4/3}$$

$$+ A_4 (T_{crit.}-T)^{5/3} + A_5 (T_{crit.}-T)^2 \ (g/mole\ cm^3) \qquad \text{Eq. (72)}$$

which is taken from Reference 19.

The constants A_1, A_2, A_3, A_4 and A_5 are listed in Appendix B as part of the hydrogen properties deck. The critical density ($\rho_{crit.}$) is taken as

$$\rho_{crit.} = 0.01559\ (g/mole\ cm^3)$$

and the critical temperature is

$$T_{crit.} = 59.357°R = 32.976°K$$

Figure No. 120 includes the flow chart of this subprogram.

(3) VPFUN

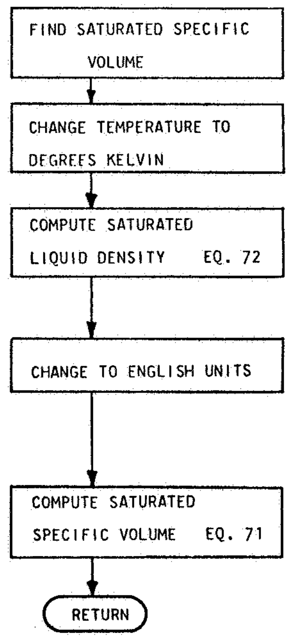
This subprogram is utilized to find hydrogen vapor pressure as a function of temperature. Reference 20 gives vapor temperature as a function of pressure; therefore, a numerical method was used to find a solution.

Vapor temperature is given by the relationship

$$T_{VP} = \{ - (B_3 \cdot B_4 + B_1 - 0.4342945\ Ln(P)) + [(B_3 \cdot B_4 + B_1 - 0.4342945\ Ln(P))^2$$

$$- 4\ B_4 (B_3 \cdot B_1 + B_2 - 0.4342945\ Ln(P))]^{1/2}\}/2\ B_4 \qquad \text{Eq. (73)}$$

FUNCTION SUBPROGRAM SVSL



FUNCTION SUBPROGRAM VPFUN

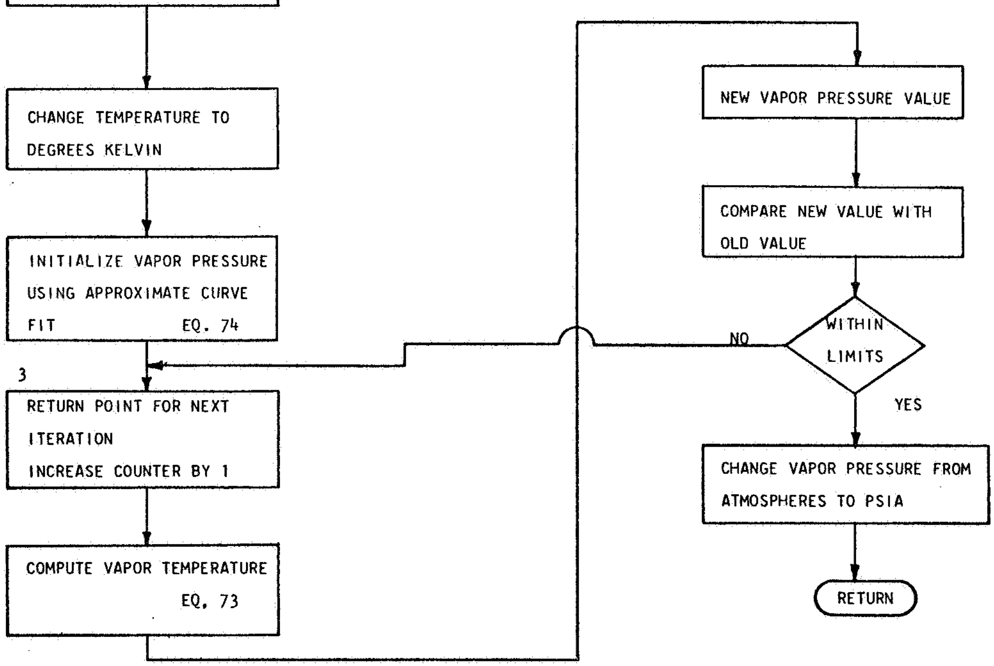


Figure 120. - Subprograms SVSL and VPFUN Flow Charts.

where:

$$B_1 = 2.00062$$

$$B_2 = -50.09708$$

$$B_3 = 1.0044$$

$$B_4 = 0.01748495$$

Ln = natural logarithm

P = pressure in atmospheres

To initiate the numerical solution of the above relationship for vapor pressure, an approximate polynominal was derived:

$$P_{VP} = (301.2628 - 17.1219\ T + 0.2549671\ T^2)/14.696\ (ATM) \quad \text{Eq. (74}$$

Figure No. 120 includes the flow chart for this subprogram.

(4) CP

Specific heat data have been curve fit for hydrogen gas as a function of temperature and pressure. These relationships are used in this subprogram to provide specific heat data for turbine calculations. For temperatures below 800°R, the relationship is

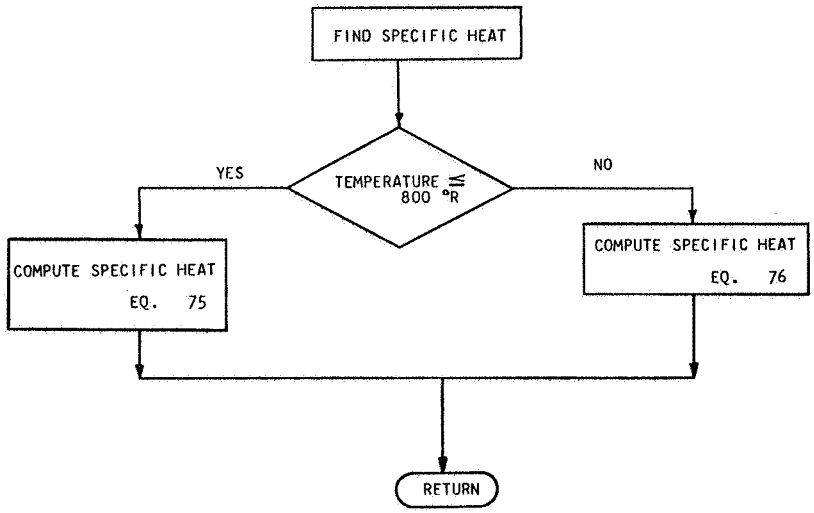
$$\begin{aligned} C_p &= 4.696 + 2.18 \times 10^{-4}\ P \\ &\quad - 1.0 \times 10^{-2}\ (0.3179 + 4.853 \times 10^{-5}\ P)\ T \\ &\quad + 1.0 \times 10^{-5}\ (0.2051 + 2.80 \times 10^{-5}\ P)\ T^2 \end{aligned} \quad \text{Eq. (75)}$$

and for temperatures above 800°R, the appropriate equation is

$$\begin{aligned} C_p &= 3.5628 + 4.453 \times 10^{-5}\ P \\ &\quad - 1.0 \times 10^{-3}\ (0.2151 + 4.773 \times 10^{-5}\ P)\ T \\ &\quad + 1.0 \times 10^{-6}\ (0.1258 + 1.293 \times 10^{-5}\ P)\ T^2 \end{aligned} \quad \text{Eq. (76)}$$

Figure No. 121 includes the flow chart for this subprogram.

FUNCTION SUBPROGRAM CP



FUNCTION SUBPROGRAM GAMMA

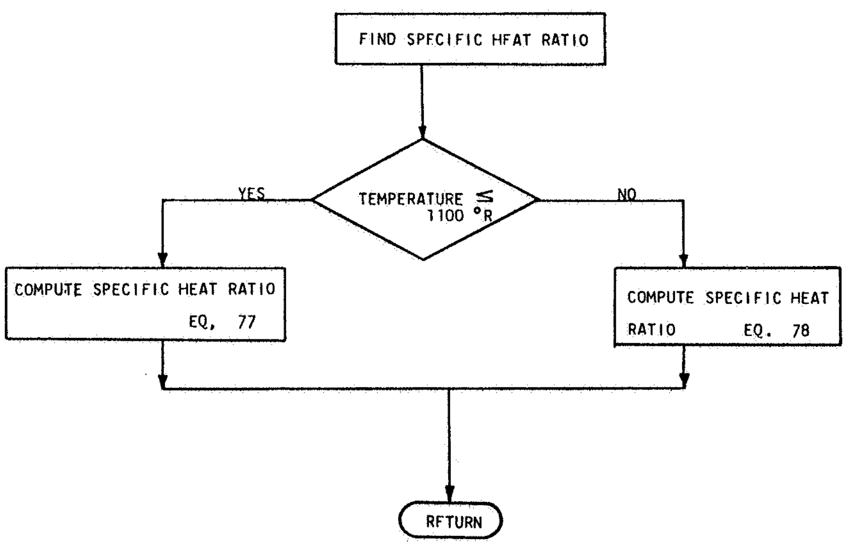


Figure 121. - Subprograms CP and GAMMA Flow Charts.

(5) GAMMA

A curve fit of the specific heat ratio (γ) as a function of pressure and temperature has been established over two temperature ranges for hydrogen gas. These curves are used in this subprogram to supply specific heat ratio data to the main program for turbine calculations. For temperatures below 1100°R, the equation used is

$$\gamma = 1.2737 + 6.286 \times 10^{-5} P + 1.0 \times 10^{-3} (0.2876 - 1.32 \times 10^{-4} P) T + 1.0 \times 10^{-6} (-0.164 + 6.92 \times 10^{-5} P) T^2 \qquad \text{Eq. (77)}$$

and for temperatures above 1100°R, the equation used is

$$\gamma = 1.4032 + 1.05 \times 10^{-5} P + 1.0 \times 10^{-5} (0.629 - 1.490 \times 10^{-3} P) T + 1.0 \times 10^{-7} (-0.1074 + 4.40 \times 10^{-5} P) T^2 \qquad \text{Eq. (78)}$$

Figure No. 121 includes the flow chart for this subprogram.

h. PRATO

The function of this subprogram is to establish an initial value for the main turbine pressure ratio based upon the power requirement (SHP_P), inlet temperature (T_i'), estimated backpressure (P_e'), and mean blade speed (U). The initial pressure ratio is corrected as indicated in the discussion of the main computer program. The original method for "initializing" the main turbine pressure ratio (Ref. 18) was found to be unstable in certain cases; therefore, it has been replaced by the method described herein.

A trial-and-error approach is applied by using the tabulated main turbine flow parameter curve. Beginning with the minimum tabulated pressure ratio, the ideal enthalpy drop is computed from the relationship

$$\Delta h_{id} = C_p \, T_i' \left[1 - \left(\frac{1}{Pr} \right)^{\frac{\gamma - 1}{\gamma}} \right] \qquad \text{Eq. (79)}$$

and the isentropic spouting velocity is

$$Co = \sqrt{2 \, g \, J \, \Delta h_{id}} \qquad \text{Eq. (80)}$$

Then, the velocity ratio, U/Co, can be determined and the corresponding main turbine efficiency, η, is found by interpolation, from the tabulated curve.

The actual enthalpy drop then is

$$\Delta h = \eta \ \Delta h_{id} \qquad \text{Eq. (81)}$$

and the main turbine inlet pressure is

$$P_i' = (P_e') \ (Pr) \qquad \text{Eq. (82)}$$

Using the flow parameter (FP) value corresponding to the pressure ratio, the weight flow rate is found

$$\dot{W} = (FP) \ (P_i')/\sqrt{T_i'} \qquad \text{Eq. (83)}$$

and the corresponding shaft power is

$$SHP_T = \frac{\dot{W} \ \Delta h \ J}{550} \qquad \text{Eq. (84)}$$

If the resulting turbine power, SHP_T, is less than the specified pump power, SHP_p, the next higher pressure ratio is utilized until $SHP_T > SHP_p$. Linear interpolation between this final value and the previous one then is made to provide the necessary initial pressure ratio (Pr_{in}).

$$Pr_{in} = Pr_n + \frac{(Pr_n - Pr_{n-1})}{SHP_{T,n} - SHP_{T,n-1}} \ (SHP_T - SHP_p) \qquad \text{Eq. (85)}$$

Figure No. 122 is the flow chart of this subprogram.

i. INLET

This subroutine is used for the waterhammer solution in the inducer suction line, with some of the logic being handled in the main program.

For transient flow in pipes, the equation of motion can be written in the following form

$$g \frac{\partial H}{\partial X} + \frac{\partial V}{\partial t} + \frac{fV}{2D} |V| = o \qquad \text{Eq. (86)}$$

and the continuity equation is

$$\frac{\partial H}{\partial t} = \frac{a^2}{g} \frac{\partial V}{\partial X} = o \qquad \text{Eq. (87)}$$

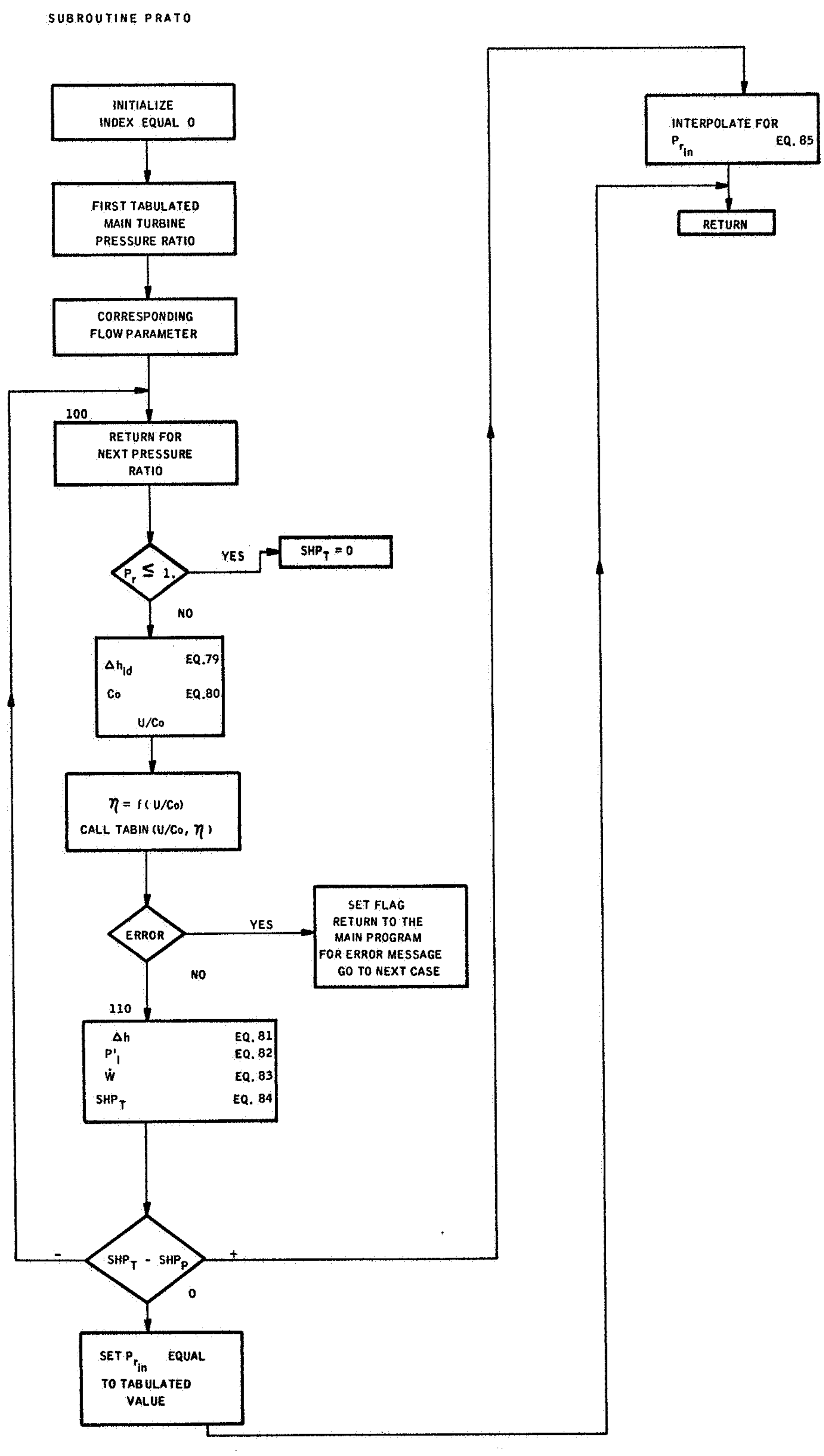


Figure 122. - Subroutine PRATO Flow Chart.

A finite difference solution to these equations is given in Reference 21 as

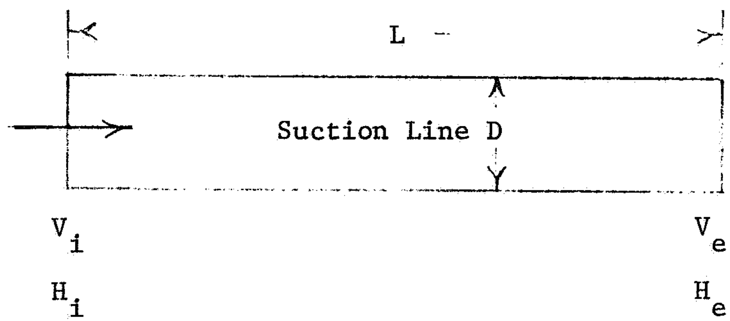
$$H_e(t) = H_i(t-\Delta t) - \frac{a}{g}\,[V_e(t) - V_i(t-\Delta t)] - \frac{f\,L}{2\,g\,D}\,V_i(t-\Delta t)\;|V_i(t-\Delta t)|$$

Eq. (88)

$$V_i(t) = V_e(t-\Delta t) + \frac{g}{a}\,[H_i(t) - H_e(t-\Delta t) - \frac{f\,L}{2\,g\,D}\,V_e(t-\Delta t)\quad V_e(t-\Delta t)]$$

Eq. (89)

where the time increment Δt is given by $\Delta t = \frac{L}{a}$ and the subscripts are as shown below:



In this case, the finite difference solution given by Equations (88) and (89) is based upon a known inlet head (H_i) or pressure and a known exit velocity (V_e). The sonic velocity used in this subprogram is for a rigid pipe. Figure No. 123 is the flow chart for this subroutine.

j. DIAG

Diagnostic messages explaining problems associated with the table interpolation subroutines are generated by using this subprogram. The messages supplied are considered to be self-explanatory.

k. OUT1

All of the computed data generated by the program is written by this subprogram at the specified time intervals. An example of the information supplied is included in Appendix B.

1. OUT2

Intermediate suction and inducer data generated between specified print intervals is written by this subprogram for transient cases involving a waterhammer solution.

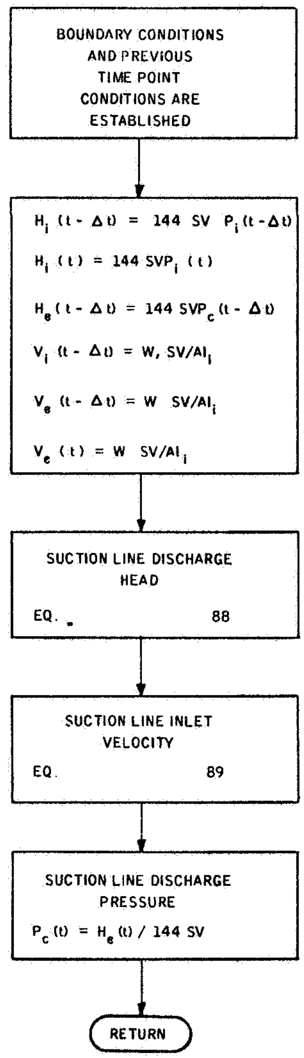


Figure 123. - Subroutine INLET Flow Chart.

m. PLOT

The logic of the main program is such that a program option (see Section VII,D) will cause the data generated by the program to be transmitted to this subroutine for processing so that a plot can be generated from it. The subroutine PLOT supplied with the program is only a dummy one which produces a diagnostic message should an attempt be made to exercise this option. This dummy subprogram can be replaced by an appropriate subprogram which is compatible with the particular computer facility wherein the program is being run. The arguments of the subprogram are as follows:

(1) Number of parameters to be plotted
(2) Data array
(3) Branch sequence number

This argument list may be changed providing a corresponding change is made in the MAIN program call sequence.

C. PROGRAM USE

This program is written in FORTRAN IV language and is suitable for use on IBM 360 system machines. Only the more basic features of FORTRAN were utilized which permits the use of lower level IBM FORTRAN compilers. Approximately 100,000 bytes of core are needed to execute the program without using overlays. Appendix A is a complete listing of the program while the FORTRAN and analysis nomenclatures are included as Appendix C.

1. Program Loading

The format for each card described in this section is illustrated on the load sheets included as Figure No. 124. Generally, floating point format is used for all real numbers except for some of the hydrogen properties data. All integer data must be right adjusted in the field. The following field specifications are shown on the load sheets (Figure No. 124):

- BCD - Any literal Alpha-numeric data
- FP - Floating point, decimal required
- I - Integer, requires right adjustment in the field

The necessary hydrogen properties deck, which is shown on the load sheets, is included in Appendix B, along with an example case. This deck is the first data for a case.

Data for each of the remaining cards is as follows:

Card 1 — This card is used for the date which is printed at the top of each page of output.

Col. 1-2 IM - Month

3-4 ID - Day

5-6 IY - Year

Card 2 — Identification card for the main turbine flow parameter curve.

Col. 1-3 K(1) - The number of "X" - "Y" pairs of data used to describe the flow parameter curve. A maximum of 30 pairs can be used.

4-8 Blank.

9-80 Any identifying literal data.

Card 3 — "X" - "Y" pairs of data from the flow parameter curve. This card is divided into fields of 10 columns and can be repeated as many times as necessary to input all points. The points must be input in the ascending order of pressure ratio.

JOB NUMBER | REPORT TITLE TWIN-SPOOL PREDICTION PROGRAM | DATE | PAGE 1 OF 5

PROGRAM LOAD SHEET HYDROGEN PROPERTIES

CARD #1

IM	ID	IY
BCD	BCD	BCD

CARD #2

K(1) I — MAIN TURBINE FLØW PARAMETER CURVE IDENTIFICATIØN — BCD

CARD #3

XT(1,1)	YT(1,1)	XT(1,2)	YT(1,2)	XT(1,3)	YT(1,3)	XT(1,4)	YT(1,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #4

K(2) I — MAIN TURBINE EFFICIENCY CURVE IDENTIFICATIØN — BCD

CARD #5

XT(2,1)	YT(2,1)	XT(2,2)	YT(2,2)	XT(2,3)	YT(2,3)	XT(2,4)	YT(2,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #6

K(3) I — INDUCER TURBINE FLØW PARAMETER CURVE IDENTIFICATIØN — BCD

CARD #7

XT(3,1)	YT(3,1)	XT(3,2)	YT(3,2)	XT(3,3)	YT(3,3)	XT(3,4)	YT(3,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #8

K(4) I — INDUCER TURBINE EFFICIENCY CURVE IDENTIFICATIØN — BCD

CARD #9

XT(4,1)	YT(4,1)	XT(4,2)	YT(4,2)	XT(4,3)	YT(4,3)	XT(4,4)	YT(4,4)
FP	FP	FP	FP	FP	FP	FP	FP

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Figure 124. Program Load Sheets (Sheet 1 of 5)

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JOB NUMBER	REPORT TITLE	DATE	PAGE
	TWIN-SPOOL PREDICTION PROGRAM		2 OF 5

PROGRAM LOAD SHEET

CARD #10

L(1)	K(5)	MAIN PUMP HEAD RISE CURVE IDENTIFICATION
I	I	BCD

CARD #11

ZP(1,1)	ZP(1,2)	ZP(1,3)	ZP(1,4)	ZP(1,5)	ZP(1,6)	ZP(1,7)	ZP(1,8)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #12

XP(1,1)	XP(1,2)	XP(1,3)	XP(1,4)	XP(1,5)	XP(1,6)	XP(1,7)	XP(1,8)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #13

YP(1,1,1)	YP(1,1,2)	YP(1,1,3)	YP(1,1,4)	YP(1,1,5)	YP(1,1,6)	YP(1,1,7)	YP(1,1,8)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #14

L(2)	K(6)	MAIN PUMP EFFICIENCY CURVE IDENTIFICATION
I	I	BCD

CARD #15

ZP(2,1)	ZP(2,2)	ZP(2,3)	ZP(2,4)	ZP(2,5)	ZP(2,6)	ZP(2,7)	ZP(2,8)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #16

XP(2,1)	XP(2,2)	XP(2,3)	XP(2,4)	XP(2,5)	XP(2,6)	XP(2,7)	XP(2,8)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #17

YP(2,1,1)	YP(2,2,1)	YP(2,3,1)	YP(2,4,1)	YP(2,5,1)	YP(2,6,1)	YP(2,7,1)	YP(2,8,1)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #18

L(3)	K(7)	INDUCER HEAD RISE CURVE IDENTIFICATION
I	I	BCD

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Figure 124. - Program Load Sheets.
(Sheet 2 of 5)

JOB NUMBER	REPORT TITLE	DATE	PAGE
	TWIN-SPOOL PREDICITON PROGRAM		3 OF 5

PROGRAM LOAD SHEET

Card	Cols 1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
CARD #19	ZP(3,1) FP	ZP(3,2) FP	ZP(3,3) FP	ZP(3,4) FP	ZP(3,5) FP	ZP(3,6) FP	ZP(3,7) FP	ZP(3,8) FP
CARD #20	XP(3,1) FP	XP(3,2) FP	XP(3,3) FP	XP(3,4) FP	XP(3,5) FP	XP(3,6) FP	XP(3,7) FP	XP(3,8) FP
CARD #21	YP(3,1,1) FP	YP(3,1,2) FP	YP(3,1,3) FP	YP(3,1,4) FP	YP(3,1,5) FP	YP(3,1,6) FP	YP(3,1,7) FP	YP(3,1,8) FP
CARD #22	L(4) I / K(8) I	INDUCER EFFICIENCY CURVE IDENTIFICATIØN BCP						
CARD #23	ZP(4,1) FP	ZP(4,2) FP	ZP(4,3) FP	ZP(4,4) FP	ZP(4,5) FP	ZP(4,6) FP	ZP(4,7) FP	ZP(4,8) FP
CARD #24	XP(4,1) FP	XP(4,2) FP	XP(4,3) FP	XP(4,4) FP	XP(4,5) FP	XP(4,6) FP	XP(4,7) FP	XP(4,8) FP
CARD #25	YP(4,1,1) FP	YP(4,1,2) FP	YP(4,1,3) FP	YP(4,1,4) FP	YP(4,1,5) FP	YP(4,1,6) FP	YP(4,1,7) FP	YP(4,1,8) FP
CARD #26	IFLAG I / JPRNT I	JFLAG I / KFLAG I	JPLØT I					
CARD #27	TMINT FP	TMAX FP	PATM FP	NIINT FP	QNM FP	TPII FP	DTIME FP	

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Figure 124. Program Load Sheets (Sheet 3 of 5)

JOB NUMBER	REPORT TITLE	DATE	PAGE
	TWIN-SPOOL PREDICTION PROGRAM		4 OF 5

PROGRAM LOAD SHEET

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CARD #28

D	XLINE	RM	RI	IMA	II	AI	AM
FP	FP	FP	FP	FP	FP	FP	FP

CARD #29

AME	XLØSS	FRI
FP	FP	FP

CARD #30

K(10)	
I	

CARD #31

XT(6,1)	YT(6,1)	XT(6,2)	YT(6,2)	XT(6,3)	YT(6,3)	XT(6,4)	YT(6,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #32

K(11)	
I	

CARD #33

XT(7,1)	YT(7,1)	XT(7,2)	YT(7,2)	XT(7,3)	YT(7,3)	XT(7,4)	YT(7,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #34

K(12)	
I	

CARD #35

XT(8,1)	YT(8,1)	XT(8,2)	YT(8,2)	XT(8,3)	YT(8,3)	XT(8,4)	YT(8,4)
FP	FP	FP	FP	FP	FP	FP	FP

CARD #36

K(13)	
I	

Figure 124. - Program Load Sheets.
(Sheet 4 of 5)

JOB NUMBER	REPORT TITLE TWIN-SPOOL PREDICTION PROGRAM	DATE	PAGE 5 OF 5

PROGRAM LOAD SHEET

CARD # 37

XT(9,1)	YT(9,1)	XT(9,2)	YT(9,2)	XT(9,3)	YT(9,3)	XT(9,4)	YT(9,4)
FP	FP	FP	FP	FP	FP	FP	FP

THIS FORM MAY BE REPRODUCED ON DIAZO PROCESS

Figure 124. - Program Load Sheets.
(Sheet 5 of 5)

Card 3 (cont.)

Col. 1-10	XT (1, 1) - first pressure ratio point (total-to-total).
11-20	YT (1, 1) - first flow parameter point.
21-30	XT (1, 2) - second pressure ratio point.
31-40	YT (1, 2) - second flow parameter point.

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Card 4 Identification card for the main turbine efficiency curve.

Col. 1-3	K (2) - The number of "X" - "Y" pairs of data used to identify the main turbine efficiency curve. A maximum of 30 pairs can be used.
4-8	Blank
9-80	Any identifying literal data.

Card 5 "X" - "Y" pairs of data from the main turbine efficiency curve. This card is divided into fields of 10 columns and can be repeated as many times as necessary. Input data must be in the ascending order of velocity ratio (U/Co).

Col. 1-10	XT (2, 1) - first velocity ratio point (based upon total-to-total pressure ratio).
	YT (2, 1) - first efficiency point (total).

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Card 6 Identification card for the inducer turbine flow parameter.

Col. 1-3	K (3) - The number of "X" - "Y" pairs of data used to identify the inducer turbine flow parameter curve.
4-8	Blank.
9-80	Any identifying literal data.

Card 7 "X" - "Y" pairs of data from the inducer flow parameter curve. The same format as Card 3.

Col. 1-10	XT (3, 1) - first pressure ratio point (total-to-total).
11-20	YT (3, 1) - first flow parameter point.

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Card 8 — Identification card for the inducer turbine efficiency curve.

Col. 1-3 — K (4) - The number of "X" - "Y" pairs of data used to identify the inducer turbine efficiency curve.

4-8 — Blank.

9-80 — Any identifying literal data.

Card 9 — "X" - "Y" pairs of data from the main turbine efficiency curve. The same format as Card 5.

Col. 1-10 — XT (4, 1) - first velocity ratio point (based upon total-to-total pressure ratio).

11-20 — YT (4, 1) - first efficiency point (static).

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Card 10 — Identification card for the main pump normalized head rise curves.

Col. 1-3 — L (1) - the number of suction-dependent, normalized head curves.

4-6 — K (5) - the number of "X" - "Y" pairs for each head rise curve.

7-8 — Blank

9-80 — Any identifying literal data.

Card 11 — Suction conditions ($NPSH/N^2$) for each main pump head rise curve in ascending order. A maximum of 10 curves can be used.

Col. 1-10 — ZP (1, 1) - first curve

11-20 — ZP (1, 2) - second curve

Card 12 — Normalized flow rate (Q/N) points for the main pump head rise curves. The same Q/N points serve as the abscissa for all of the head curves. Repeat card as many times as necessary.

Col. 1-10 — XP (1, 1) - first Q/N point.

11-20 — XP (1, 2) - second Q/N point.

Card 13 — Ordinates of the main pump normalized heat rise curves, corresponding to the Q/N of card 12 (i.e., values of $\Delta H/N^2$). Repeat this card as many times as necessary. Start with the first field of the card for each curve.

Col. 1-10 — YP (1, 1, 1) - first point, curve 1.

11-21 — YP (1, 1, 2) - second point, curve 1.

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Card 13 (cont.)

Col. 1-10 YP (1, 2, 1) - first point, curve 2.

11-21 YP (1, 2, 2) - second point, curve 2.

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Card 14 Main pump efficiency curve identification card.

Col. 1-3 L (2) - the number of suction-dependent, efficiency curves.

4-6 K (6) - the number of "X" - "Y" pairs for each efficiency curve.

7-8 Blank.

9-80 Any identifying literal data.

Card 15 Suction conditions ($NPSH/N^2$) for each main pump efficiency curve in ascending order. A maximum of 10 curves can be used.

Col. 1-10 ZP (2, 1) - first curve.

11-20 ZP (2, 2) - second curve.

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Card 16 Normalized flow rate (Q/N) points for the main pump efficiency curves. The same Q/N points serve as the abscissa for all efficiency curves. Repeat card as many times as necessary.

Col. 1-10 XP (2, 1) - first Q/N point.

11-20 XP (2, 2) - second Q/N point.

Card 17 Ordinates of the main pump efficiency curve corresponding to the Q/N points of card 16 (i.e., values of efficiency). Repeat this card as many times as necessary. Start with the first field of the card for each curve.

Col. 1-10 YP (2, 1, 1) - first point, curve 1.

11-20 YP (2, 1, 2) - second point, curve 1.

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1-10 YP (2, 2, 1) - first point, curve 2.

11-20 YP (2, 2, 2) - second point, curve 2.

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Card 18 — Inducer normalized head rise curve identification card.

Col. 1-3 — L (3) - the number of suction-dependent, inducer head rise curves.

4-6 — K (7) - the number of "X" - "Y" pairs for each head rise curve.

7-8 — Blank.

9-80 — Any identifying literal data.

Card 19 — Suction conditions ($NPSH/N^2$) for each inducer head rise curve in ascending order. A maximum of 10 curves can be used.

Col. 1-10 — ZP (3, 1) - first curve.

ZP (3, 2) - second curve.

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Card 20 — Normalized flow rate (Q/N) points for the inducer head rise curves. The same Q/N points are used for all head rise curves. Repeat card as many times as necessary.

Col. 1-10 — XP (3, 1) - first Q/N point.

11-20 — XP (3, 2) - second Q/N point.

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Card 21 — Ordinates of the inducer normalized head rise curves corresponding to the Q/N of card 20 (i.e., values of $\Delta H/N^2$). Repeat this card as many times as necessary. Start with the first field of the card for each curve.

Col. 1-10 — YP (3, 1, 1) - first point, curve 1.

11-20 — YP (3, 1, 2) - second point, curve 1.

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1-10 — YP (3, 2, 1) - first point, curve 2.

11-20 — YP (3, 2, 2) - second point, curve 2.

Card 22 — Inducer efficiency curve identification card.

Col. 1-3 — L (4) - the number of suction-dependent, inducer head rise curves.

4-6 — K (8) - the number of "X" - "Y" pairs for each efficiency curve.

Card 22 (cont.)

Col. 7-8 Blank.

9-80 Any identifying literal data.

Card 23 Suction conditions ($NPSH/N^2$) for each inducer efficiency curve in ascending order. A maximum of 10 curves can be used.

Col. 1-10 ZP (4, 1) - first efficiency curve.

ZP (4, 2) - second efficiency curve.

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Card 24 Normalized flow rate (Q/N) points for the inducer efficiency curves. The same Q/N points are used for all efficiency curves. Repeat card as many times as necessary.

Col. 1-10 XP (4, 1) - first Q/N point.

XP (4, 2) - second Q/N point.

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Card 25 Ordinates of the inducer efficiency curves corresponding to the Q/N points of card 24 (i.e., values of efficiency). Repeat this card as many times as necessary. Start with the first field of the card for each curve.

Col. 1-10 YP (4, 1, 1) - first point, curve 1.

11-20 YP (4, 1, 2) - second point, curve 1.

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1-10 YP (4, 2, 1) - first point, curve 2.

11-20 YP (4, 2, 2) - second point, curve 2.

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Card 26 — This is the first card of the particular case involving a set of specified operating conditions. The several program options are controlled by the control flags of this card.

Col. 1-5 — IFLAG - 1 if turbine inlet pressure is input as the independent parameter; 2 if main shaft speed is input as the independent parameter.

6-10 — JPRNT - this is the print interval for transient cases (i.e., 1 if output for every computed time point; 2 if output for every second computed time point; etc.). The first, second, and last time points always are printed regardless of the value of JPRNT.

11-15 — JFLAG - 1 if suction line waterhammer solution is to be used; 2 if no waterhammer solution.

16-20 — KFLAG - 1 if steady-state point; 2 if transient case.

21-25 — JPLOT - 0 if no plots; 1 if all time points plotted; 2 if only printed time points are to be plotted. No plot subroutine is included with the program because plotting is an off-line operation, which is unique to a particular computer facility. However, this program option can be utilized by replacing the dummy plot subprogram (PLOT) with a subprogram suited to the particular facility.

Card 27 — This card contains the information pertinent to a certain set of operating conditions.

Col. 1-10 — TMINT - initial time for a transient case or 0.0 for a steady-state case.

11-20 — TMAX - final time for a transient case; 0.0 for a steady-state case if another case follows; and any number >0.0 for the final steady-state case.

21-30 — PTTEM - Estimated main turbine exhaust total pressure (for the initial time for a transient case). This value will be modified to the correct value by the program through successive iterations.

31-40 — NIINT - estimated inducer shaft speed (for the initial time if a transient case).

41-50 — QNM - main pump Q/N.

51-60 — TPII - temperature of the fluid at the inducer inlet.

61-70 — DTIME - computing time interval for transient cases if the waterhammer solution is not used.

Card 28 — Geometry parameters.

Col. 1-10 — D - Suction line diameter.

11-20 — XLINE - Suction line length.

21-30 — RM - Mean blade radius at main turbine.

Card 28 (cont.)

Col.	31-40	RI - Mean blade radius of inducer turbine.
	41-50	IMA - Main rotating assembly polar moment of inertia.
	51-60	II - Inducer rotating assembly polar moment of inertia.
	61-70	AI - Inducer inlet flow area.
	71-30	AM - Main pump inlet flow area.

Card 29 Geometry, continued.

Col.	1-10	AME - Main pump discharge flow area.
	11-20	XLOSS - Turbine exhaust system loss coefficient.
	21-30	FRI - Suction line friction factor.

Card 30 First card of the time dependent operating parameters.

Col. 1-5 K (10) - Number of "X" - "Y" pairs of data used to describe the turbine inlet temperature as a function of time.

Card 31 "X" - "Y" pairs of data for turbine inlet total temperature-time relation. Repeat card as many times as necessary.

Col.	1-10	XT (6, 1) - first time point.
	11-20	YT (6, 1) - first temperature.
	21-30	XT (6, 2) - second time point.
	31-40	YT (6, 3) - second temperature.

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Card 32

Col. 1-5 K (11) - Number of "X" - "Y" pairs of data used to describe the turbine inlet total pressure as a function of time.

Card 33 "X" - "Y" pairs of data for turbine inlet total pressure-time relation. Repeat as many times as necessary.

Col.	1-10	XT (7, 1) - first time point.
	11-20	YT (7, 1) - first pressure.
	21-30	XT (7, 2) - second time point.
	31-40	YT (7, 2) - second pressure.

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Card 34

Col. 1-5 K (12) - Number of "X" - "Y" pairs of data used to describe the main shaft speed as a function of time. At least one data pair must be input corresponding to the initial time point if option (IFLAG=1) is being used. This amounts to an initial estimate of main shaft speed and will be modified by the program.

Card 35 "X" - "Y" pairs of data for main shaft speed-time relation. Repeat card as many times as necessary.

Col. 1-10 XT (8, 1) - first time point.

11-20 YT (8, 1) - first speed point.

21-30 XT (8, 2) - second time point.

31-40 YT (8, 2) - second speed point.

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Card 36

Col. 1-5 K (13) - Number of "X" - "Y" pairs of data used to describe the tank pressure as a function of time.

Card 37 "X" - "Y" pairs of data for the tank pressure-time relation. Repeat card as many times as necessary.

Col. 1-10 XT (9, 1) - first time point.

11-20 YT (9, 1) - first tank pressure point.

21-30 XT (9, 2) - second time point.

31-40 YT (9, 2) - second tank pressure point.

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.
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2. Program Restrictions

The tabulated data used to represent the turbopump characteristics must be interpolated for all operating points; therefore, it is necessary that the characteristic curves be extended to cover the range of operating points as well as all points reached in any intermediate iteration loops. No provision has been made for extending the tabulated data and any condition encountered which forces a search for data outside the confines of the table will result in a diagnostic message as well as termination of the case.

It is possible that cases involving extremely low speeds will not be executed because an insufficient number of significant digits are available to close some of the necessary iteration loops.

This program is restricted to use with hydrogen as the turbine drive gas and pumped fluid unless the fluid properties subprograms are replaced with ones suited for another fluid. Also, the range of operation is restricted to that covered by the properties subprograms.

D. COMPUTER PROGRAM VERIFICATION AND REFINEMENT

1. Verification

Verification of the analytical model used to predict the operating characteristics of twin-spool turbopumps was demonstrated by comparing analytical results with the test data obtained during twin-spool testing in hydrogen.

The capability of the computer program to predict transient performance which is typical of that experienced during engine start transients is of primary interest. Therefore, a comparison between analytically determined performance and actual test performance is made here for two typical engine start ramps of six seconds and three seconds, respectively.

The characteristic curves used in the computer analyses are shown on Figures No. 125 through No. 130. These curves were derived from the test data obtained during the twin-spool test series. The turbine characteristic curves (Figures No. 125 through No. 128) are based upon the best-fit of the test data and should not be confused with the prediction curves shown elsewhere in this report. The inducer and pump efficiency curves deviate from the raw test data inasmuch as an inducer stator discharge temperature correction was made. The ramifications of this correction were discussed earlier in the pump and inducer sections.

Several of the more important parameters associated with the twin-spool turbopump operation during the 6 sec ramp of Test No. -003 are shown on Figures No. 131 through No. 136 along with analytical results for the same parameters using the computer model. The computer analytical results are based upon the time-dependent test data (tank pressure, turbine inlet total temperature, and turbine inlet total pressure) shown on Figure No. 131.

The main shaft speed for the 6 sec transient analysis shown on Figure No. 132 is higher than it actually was during the initial phase of the transient. This is at least partially attributable to the turbine inlet pressure indication resulting from the bearing coolant flow through the turbine prior to start-up.

The initial deviation in pump pressure rise (see Figure No. 133) is directly related to the difference between the analytically determined speed and the test speed discussed above. The computer model was based upon the assumption that normalized pump flow be maintained at a constant value during transient operation. Any drift from a constant value during testing results in some deviation between the analytical and actual test results.

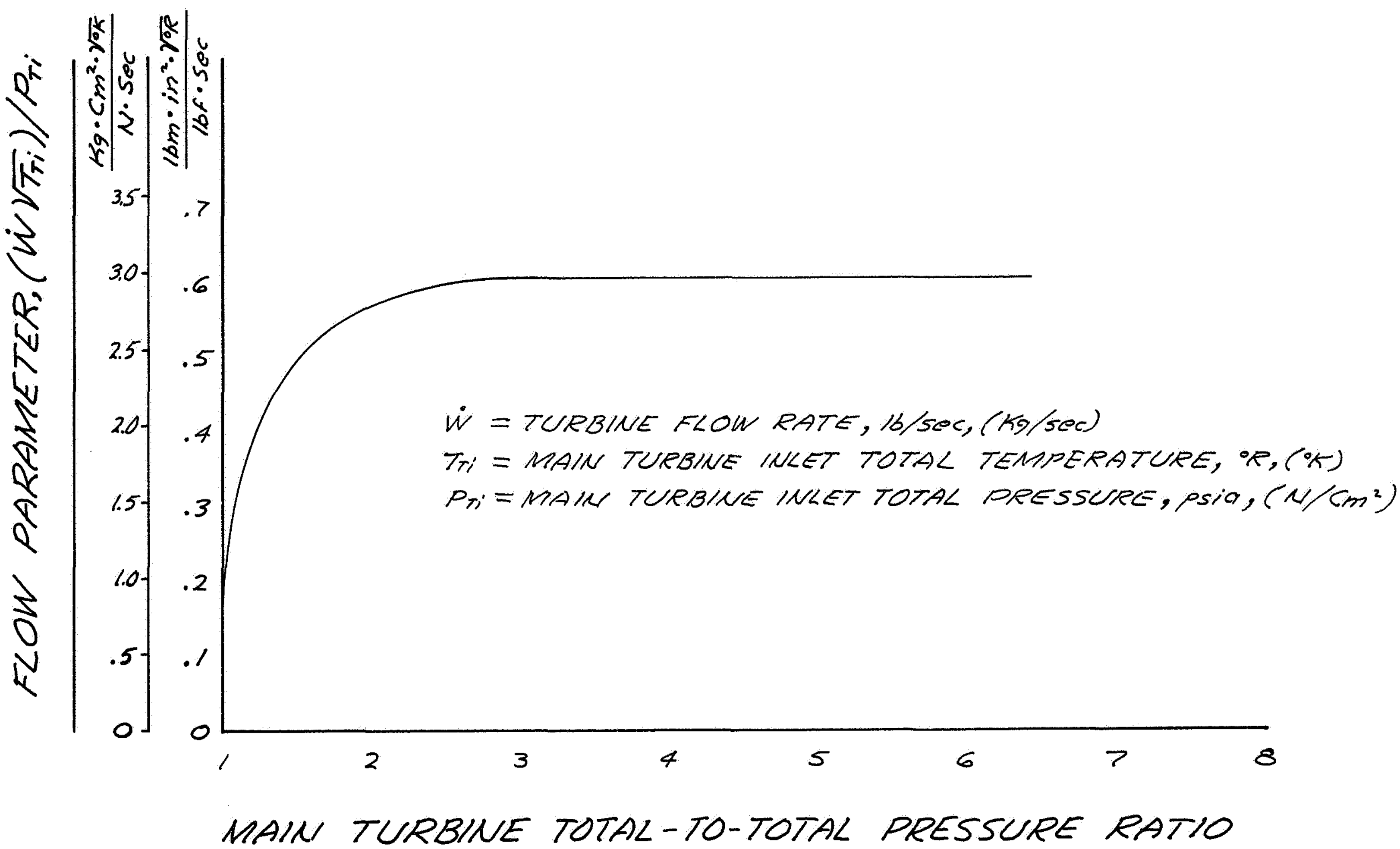

Figure 125. - Computer Model Characteristic Curve, Main Turbine Flow Parameter.

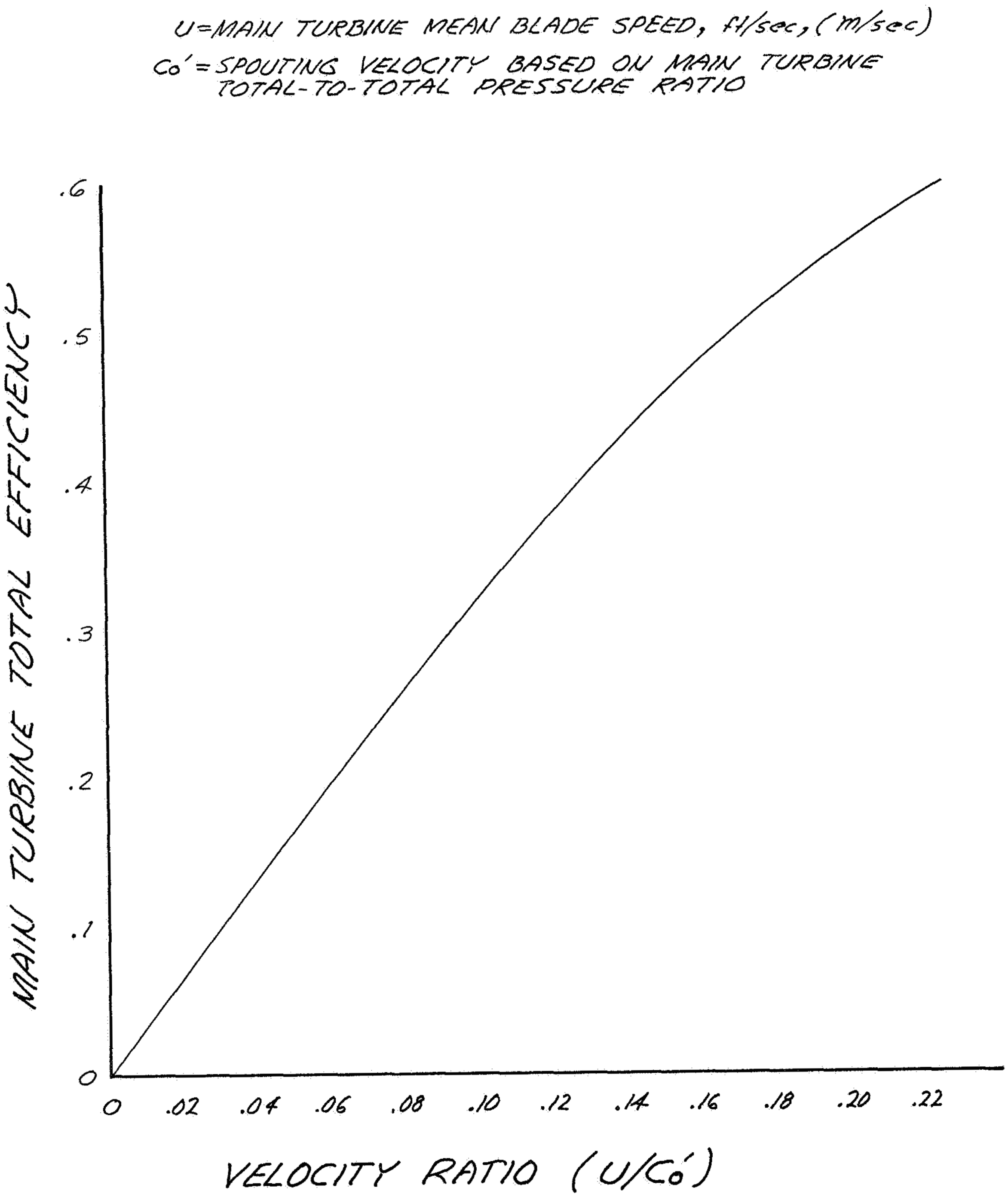

Figure 126. - Computer Model Characteristic Curve, Main Turbine Total Efficiency.

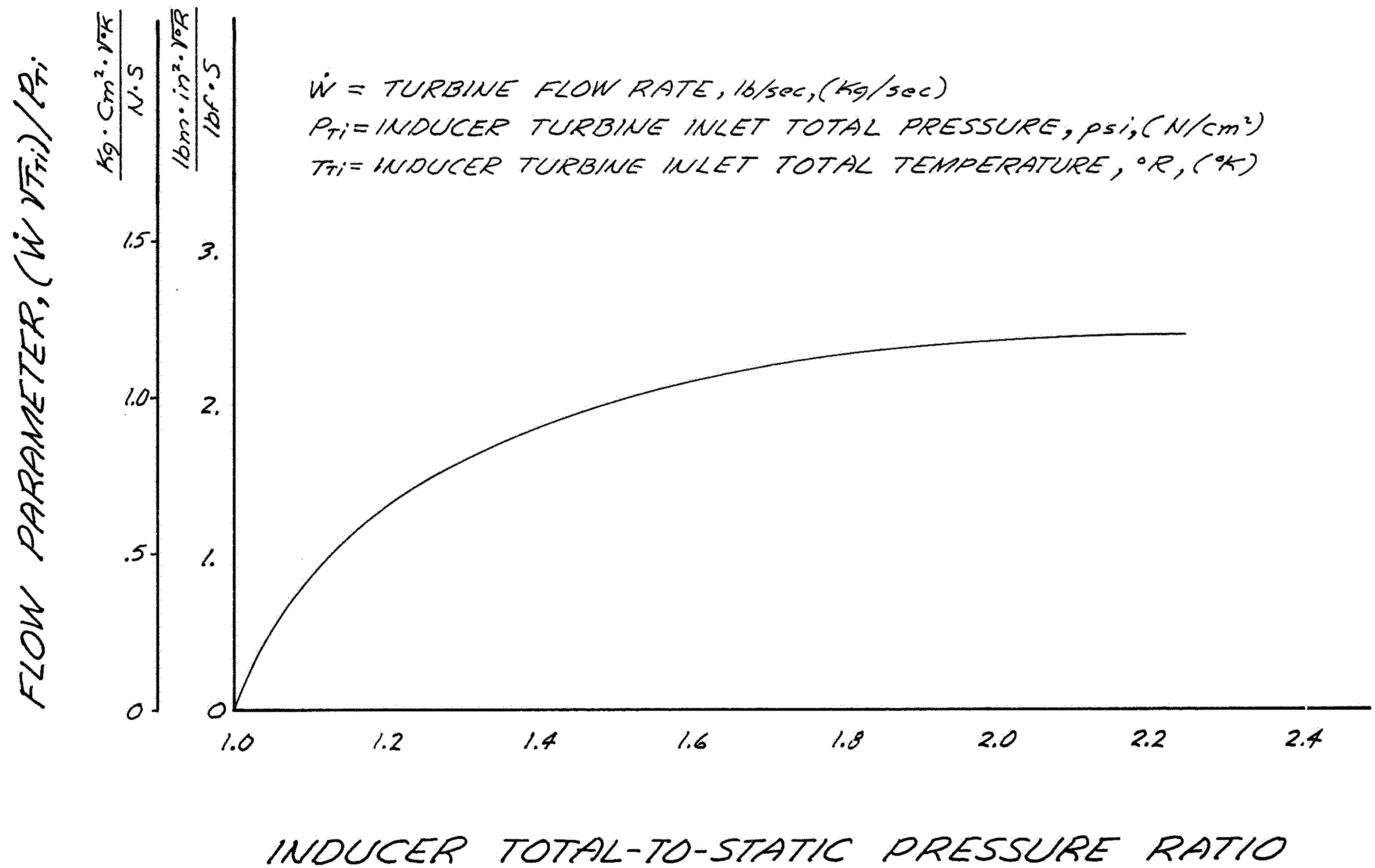

Figure 127. Refined Characteristic Curve, Inducer Turbine Flow Parameter

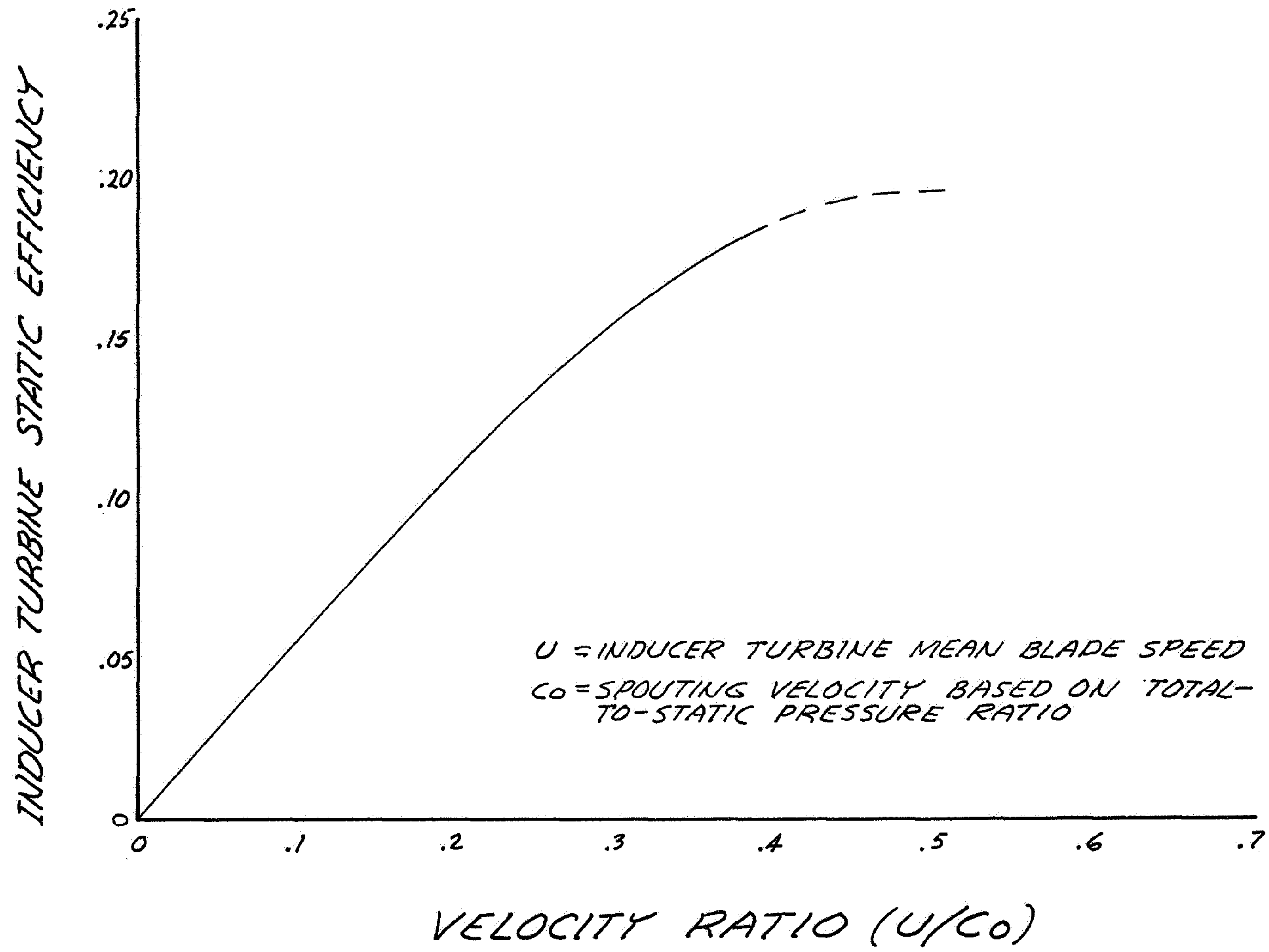

Figure 128. Refined Characteristic Curve, Inducer Turbine Static Efficiency

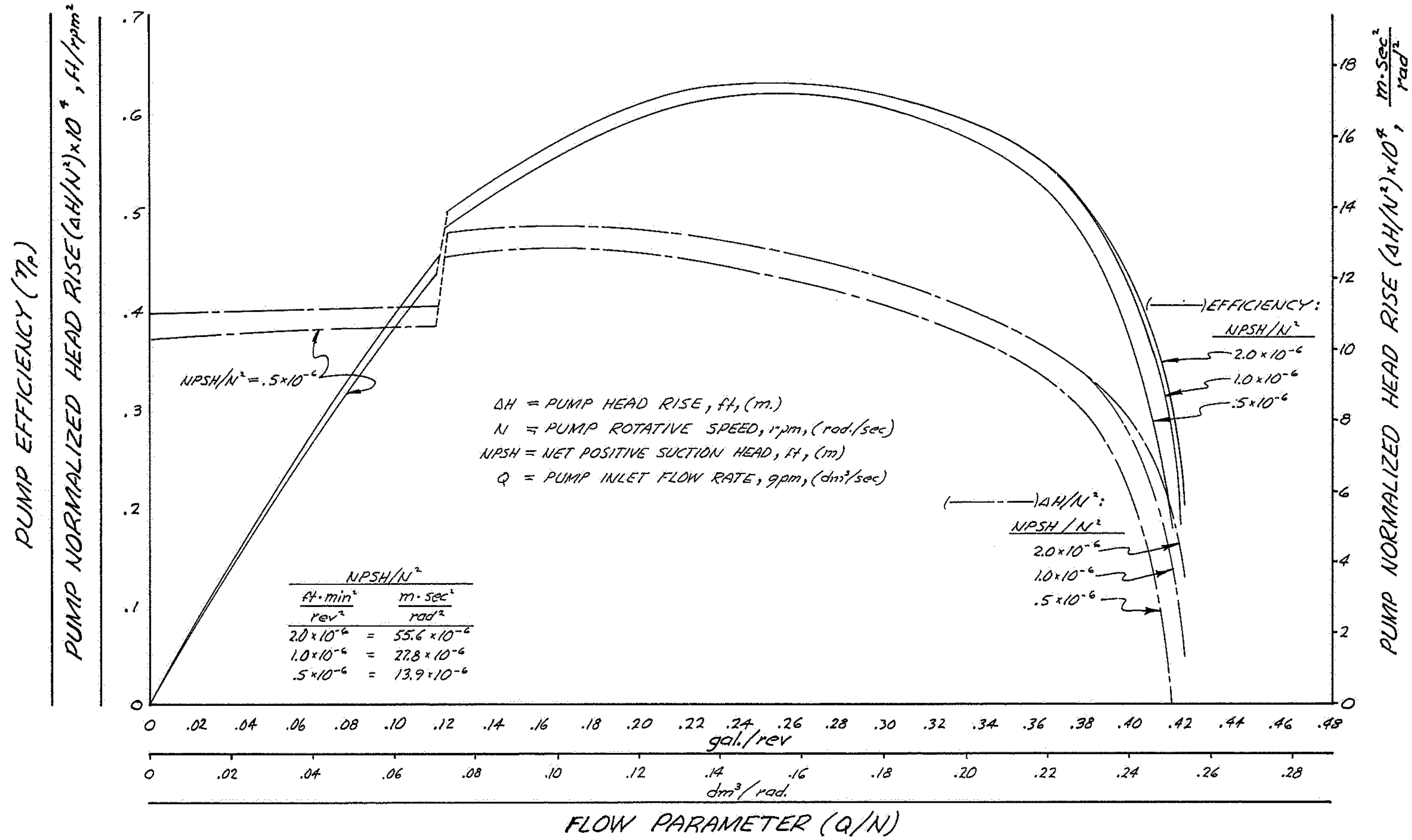

Figure 129. Refined Characteristic Curve, Inducer Turbine and Normalized Head Rise

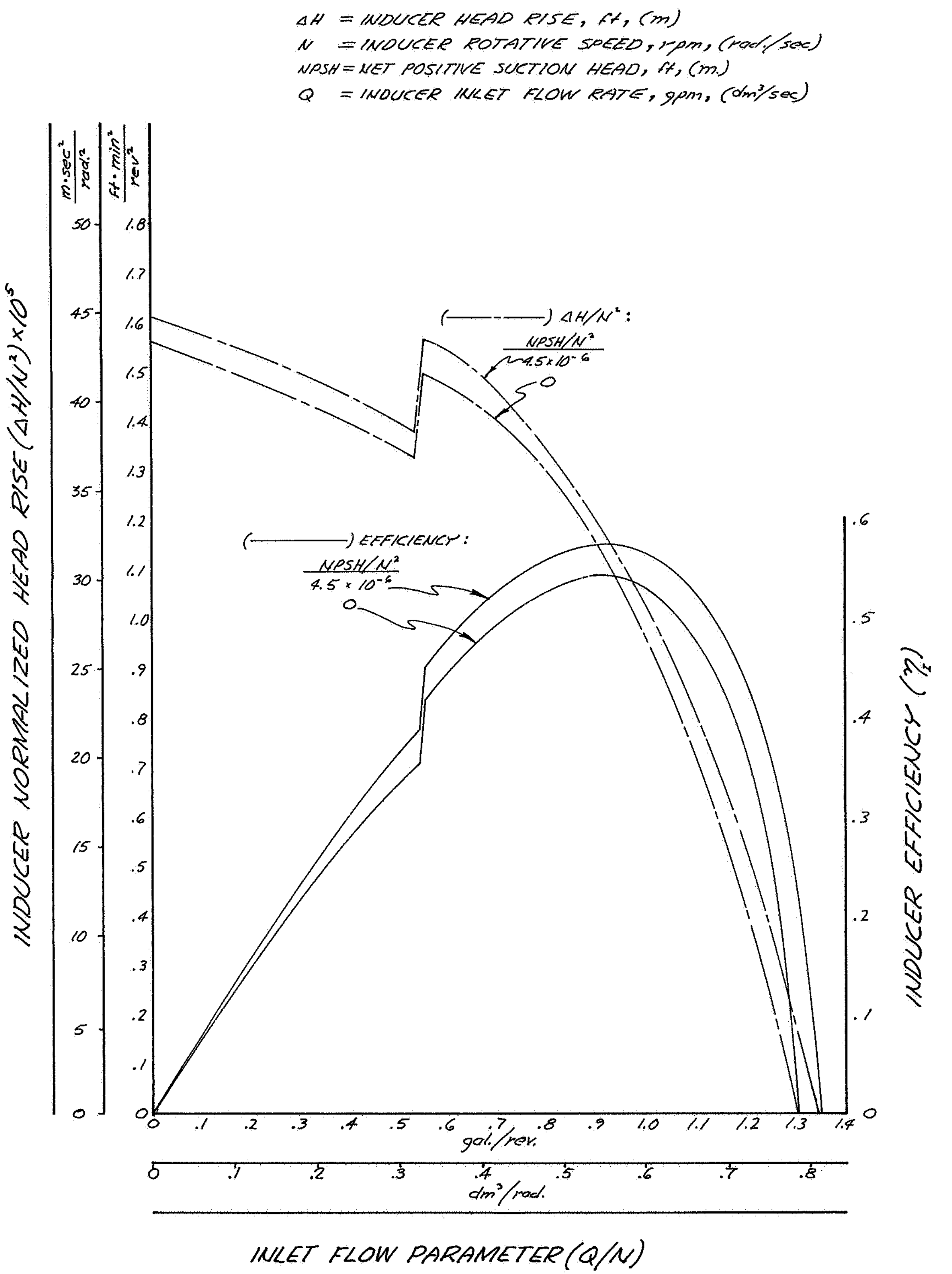

Figure 130. Refined Characteristic Curve, Inducer Turbine Efficiency and Normalized Head Rise

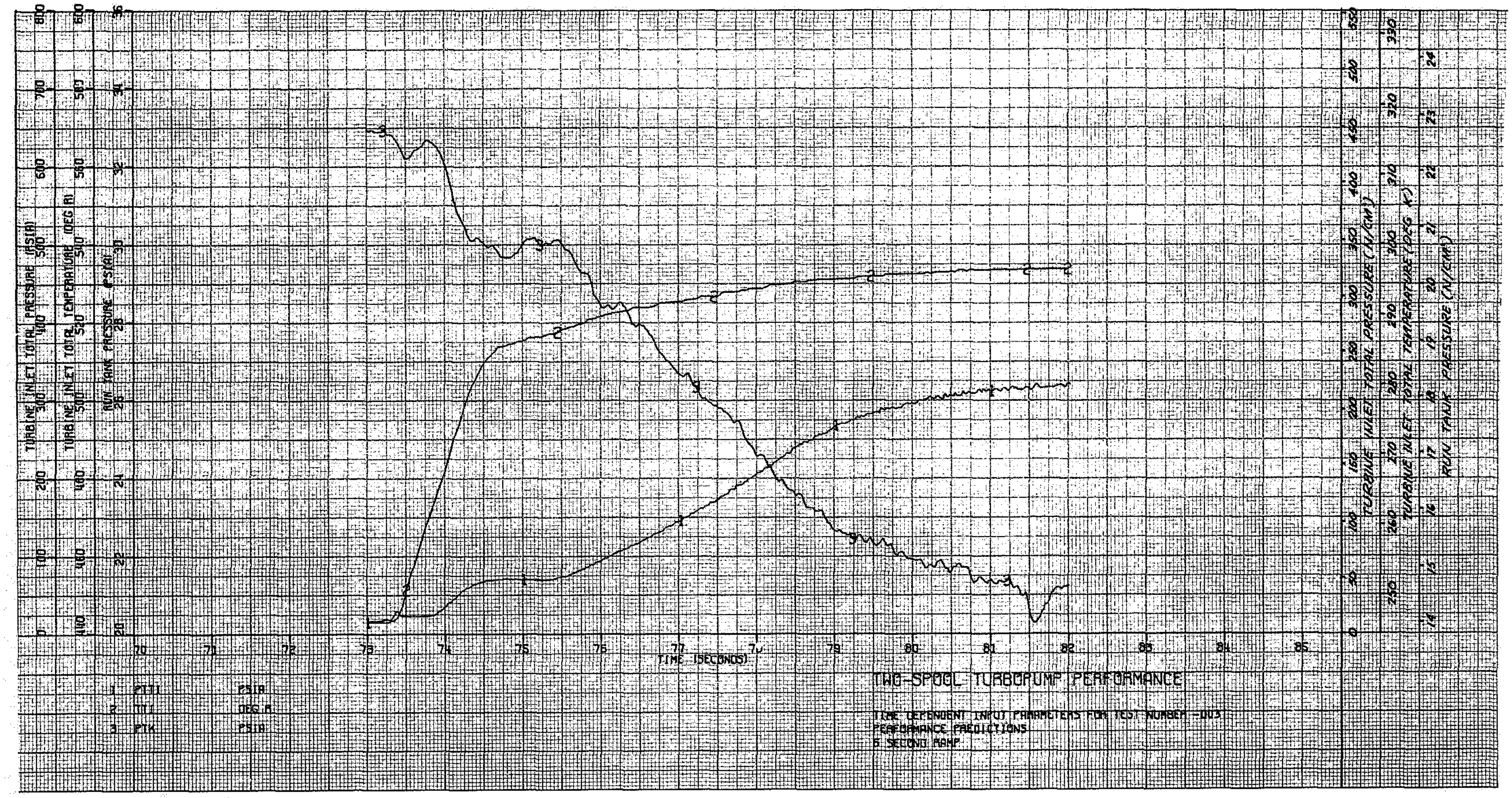

Figure 131. - Two-Spool Turbopump Performance, Time-Dependent Input Parameters, Test No. -003.

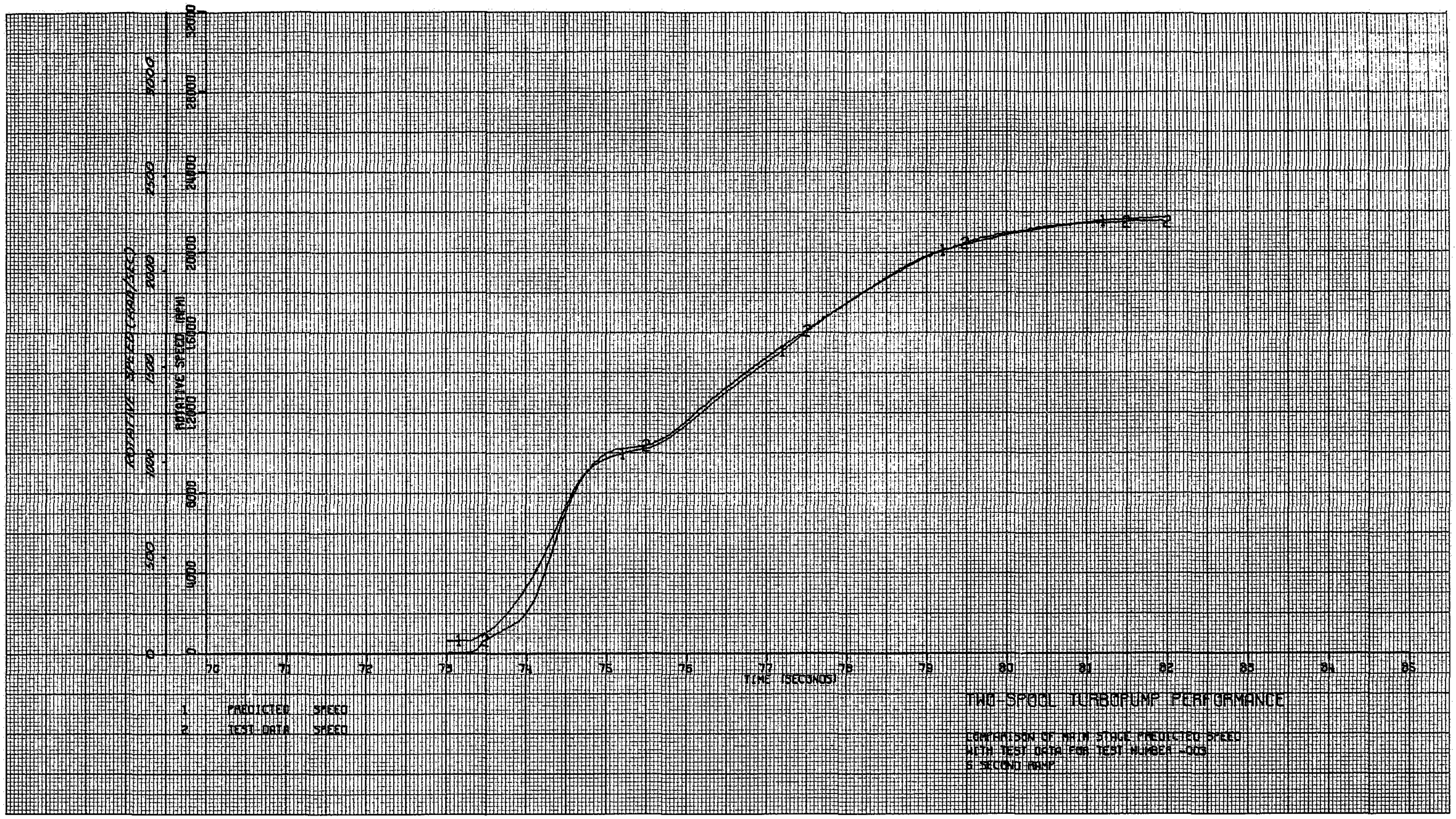

Figure 132. - Two-Spool Turbopump Performance, Pump Predicted Speed vs Pump Actual Speed, Test No. -003.

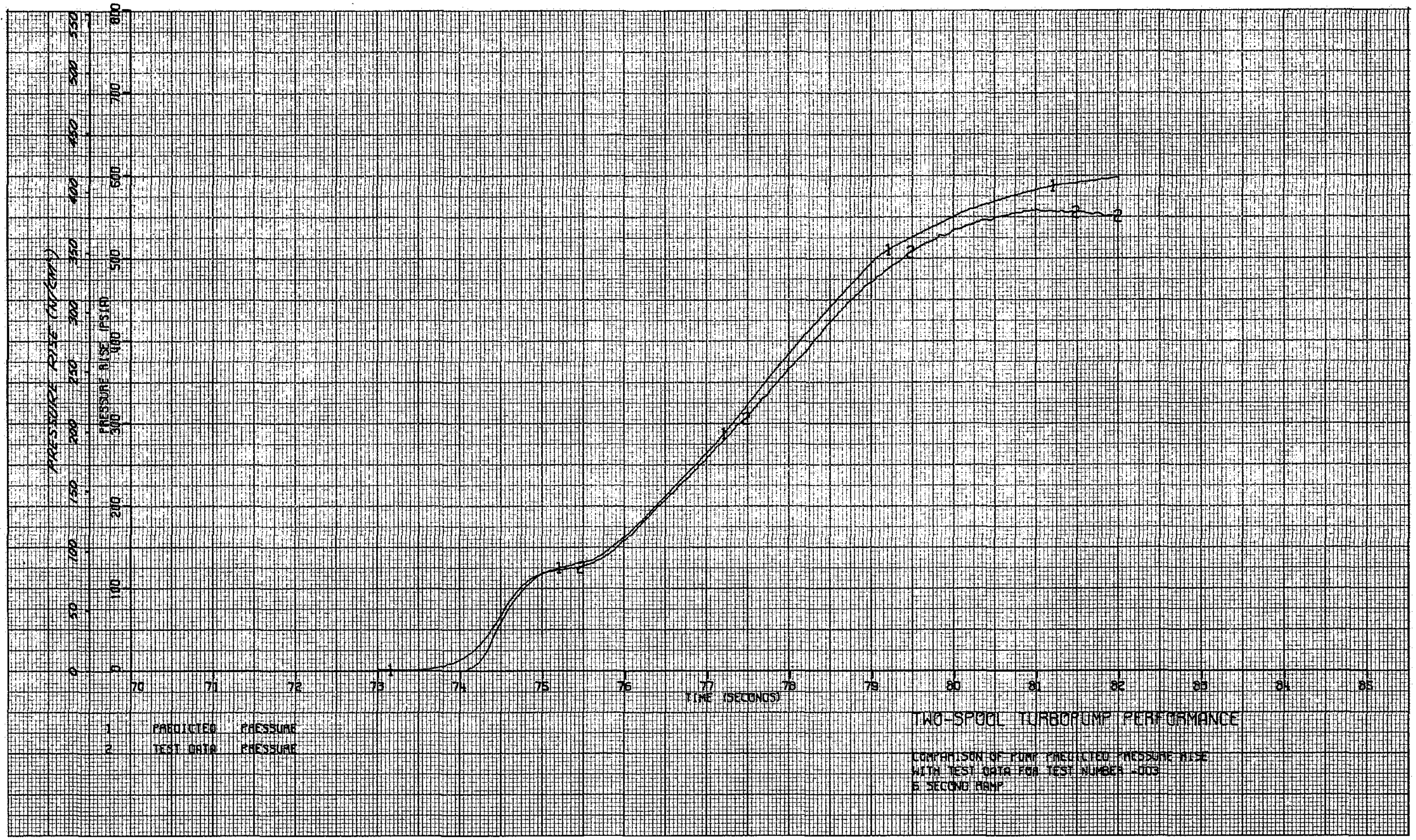

Figure 133. - Two-Spool Turbopump Performance, Pump Predicted Pressure Rise vs Pump Actual Pressure Rise, Test No. -003.

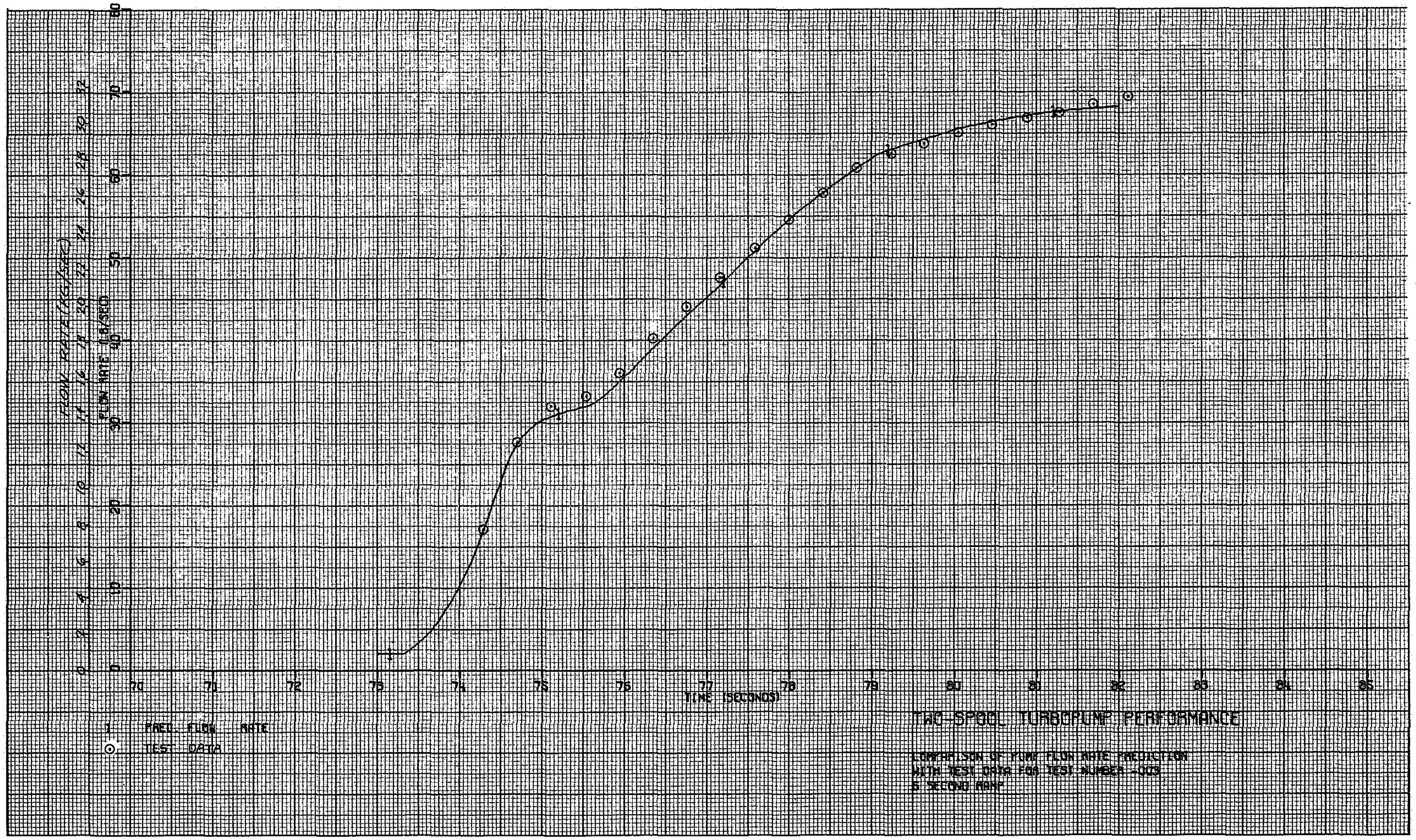

Figure 134. - Two-Spool Turbopump Performance, Pump Predicted Flow Rate vs Pump Actual Flow Rate, Test No. -003.

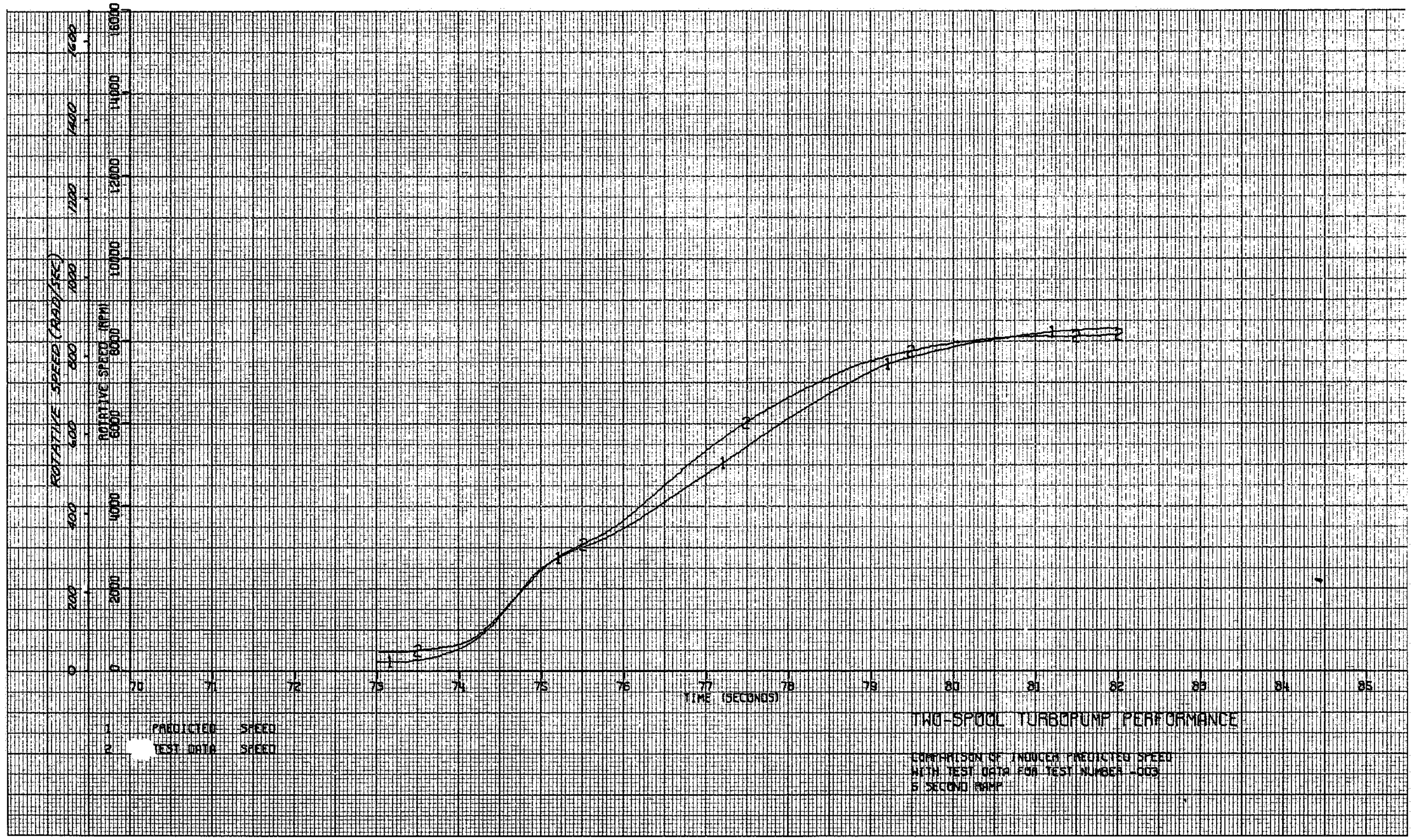

Figure 135. - Two-Spool Turbopump Performance, Inducer Predicted Speed vs Inducer Actual Speed, Test No. -003.

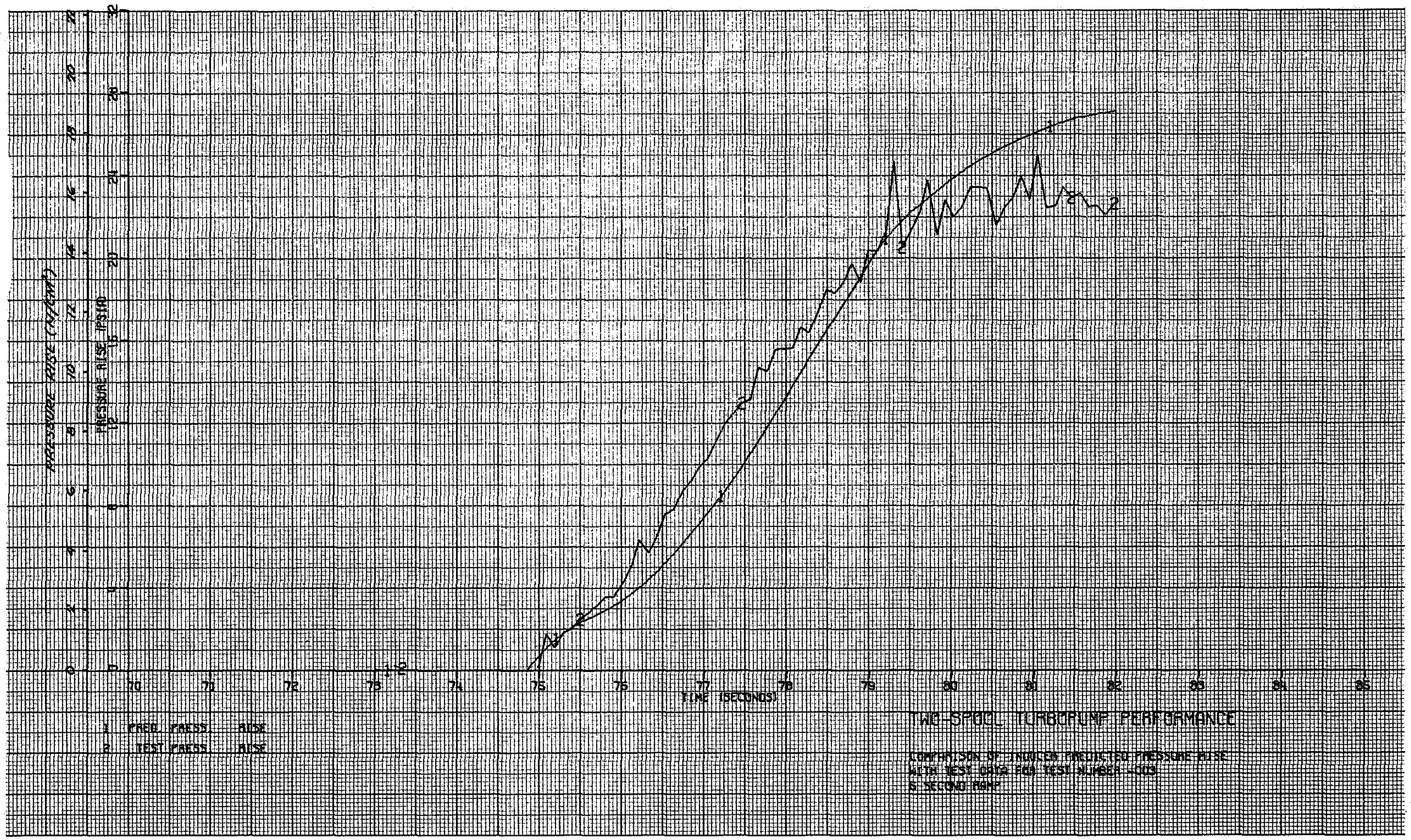

Figure 136. - Two-Spool Turbopump Performance, Inducer Predicted Pressure Rise vs Inducer Actual Pressure Rise, Test No. -003.

There is a slight difference between the pump flow rate determined analytically and the test results near the end of the transient shown on Figure No. 134. Again, this is a result of the drift in the normalized pump flow.

The inducer speed for the 6 sec ramp is plotted on Figure No. 135. Indications are that the higher acceleration rate experienced during the test is the result of an inability to accurately obtain the polar moment of inertia for the inducer rotating assembly because of the inducer vanes. A slightly lower value than that used in the analysis would yield results more nearly in agreement with the test results.

It is believed that the erratic nature of the inducer pressure rise (see Figure No. 136) obtained from the test data was the result of instrumentation and vibration influences. An accurate comparison between analytical and test results for this parameter was not possible.

Similar analytical results and test data for the 3 sec transient test (-004) are provided on Figures No. 137 through No. 142.

The digital data from the 6 sec analysis is included in Appendix B as part of the example.

2. <u>Refinements</u>

The following minor refinements were made to the original computer model (Ref. 18) as a result of program usage experience and test data evaluation:

a. It was found that the numerical root finding technique used to initiate main turbine pressure ratio was unstable in certain cases. Therefore, this program segment was replaced by a more stable method.

b. The assumption that the time-dependent input data, turbine inlet pressure or main shaft speed, depending upon the option being exercised, and turbine inlet temperature could be represented by second order polynomials in time proved inadequate because of the erratic nature of this data. The problem was solved by using tabulated data as a function of time to represent these parameters with linear interpolation between tabulated points.

c. The characteristic curves used to represent the turbopump components were corrected upon the basis of test data.

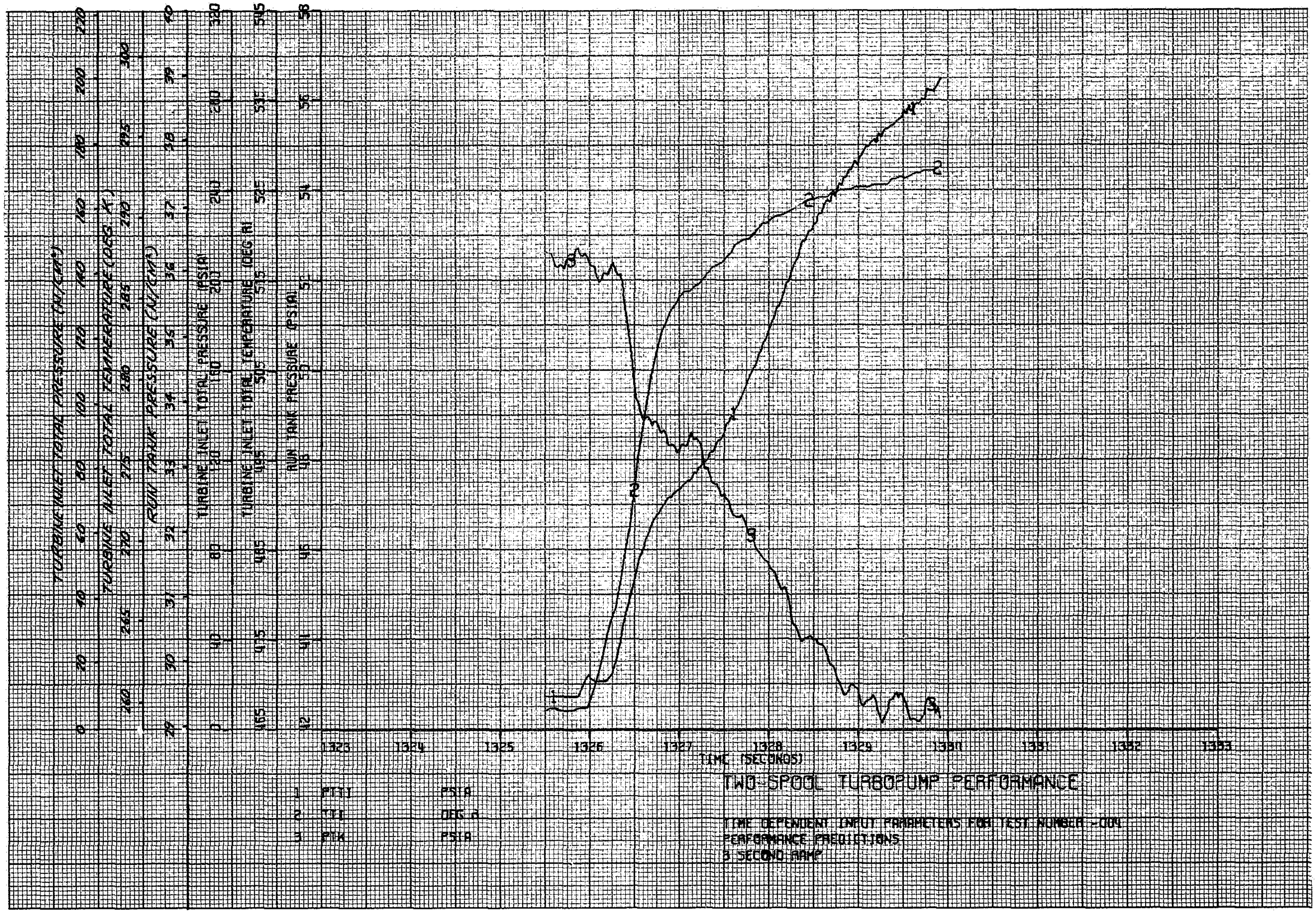

Figure 137. - Two-Spool Turbopump Performance, Time-Dependent Input Parameters, Ntest No. -004.

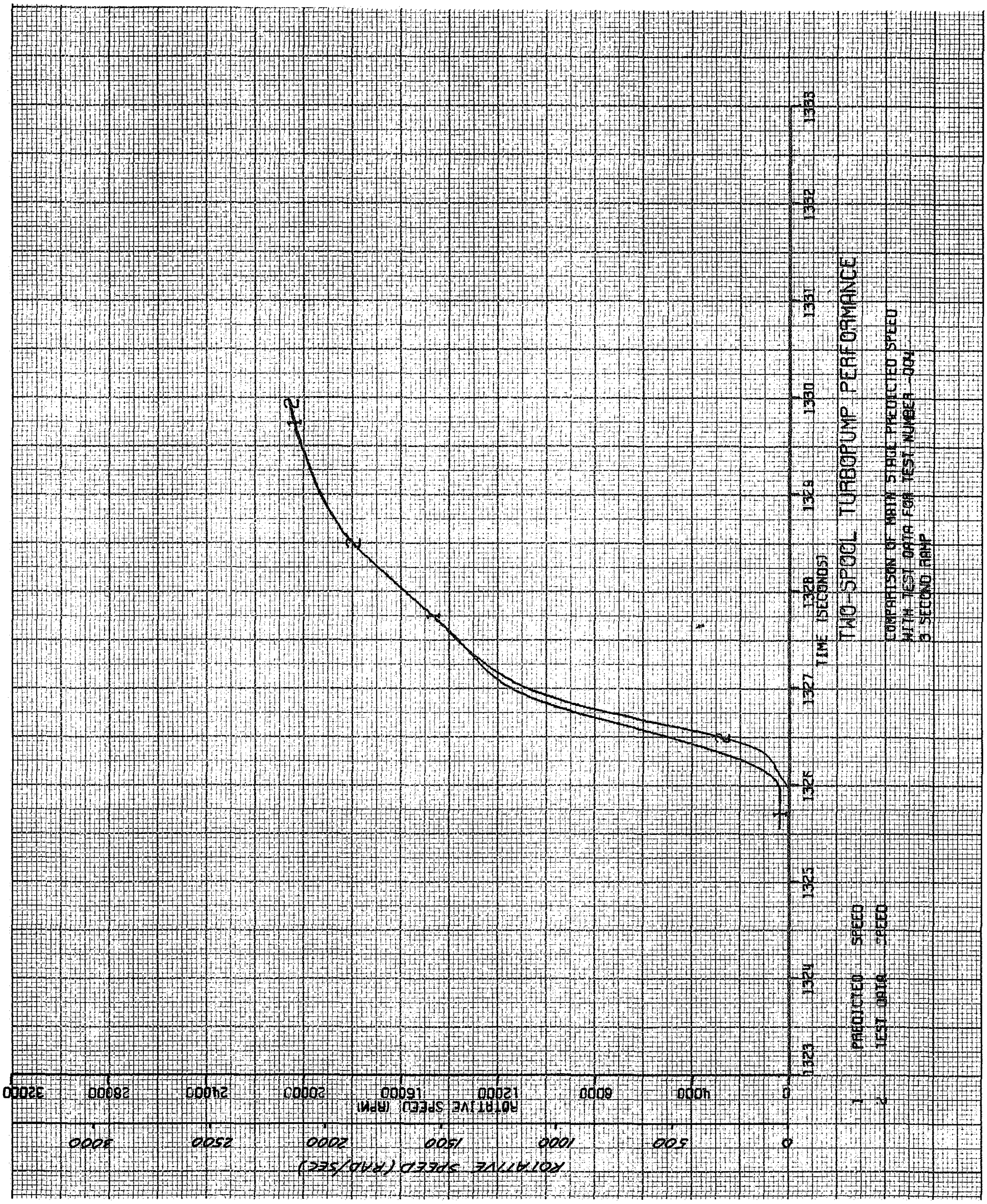

Figure 138. - Two-Spoll Turbopump Performance, Pump Predicted Speed vs Pump Actual Speed, Test No. -004.

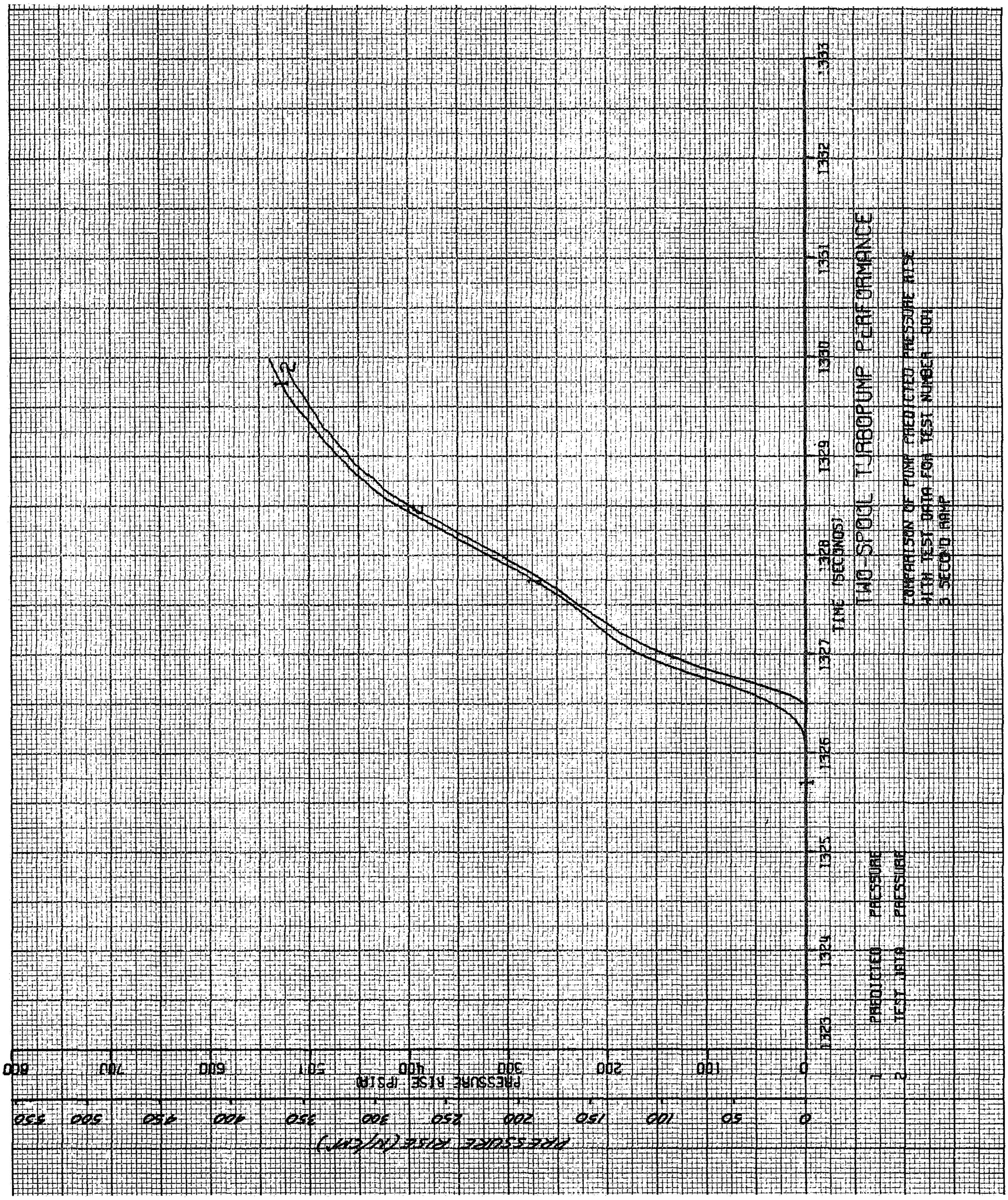

Figure 139. - Two-Spool Turbopump Performance, Pump Predicted Pressure Rise vs Pump Actual Pressure Rise, Test No. -004.

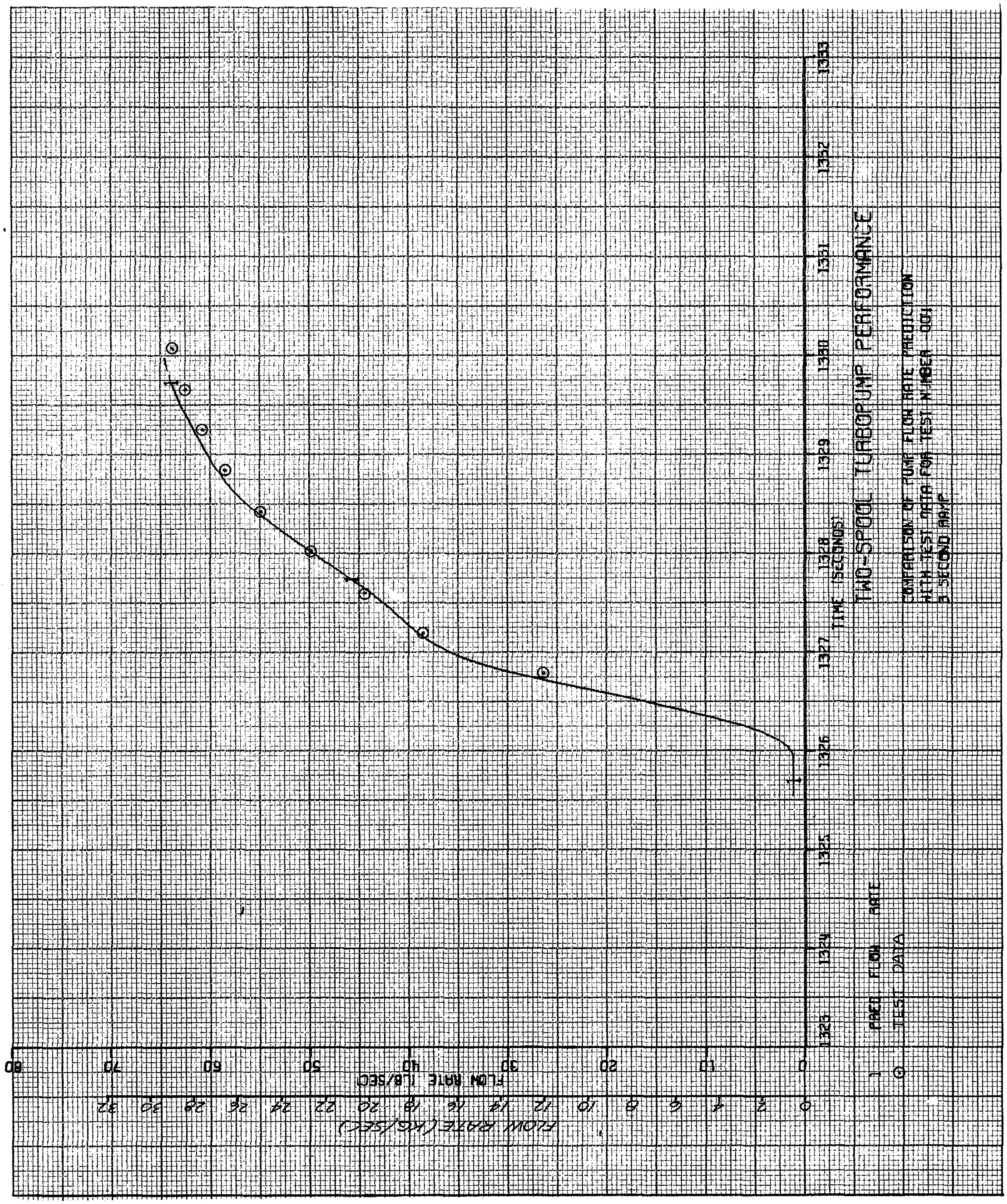

Figure 140. - Two-Spool Turbopump Performance, Pump Predicted Flow Rate vs Pump Actual Flow Rate, Test No. -004.

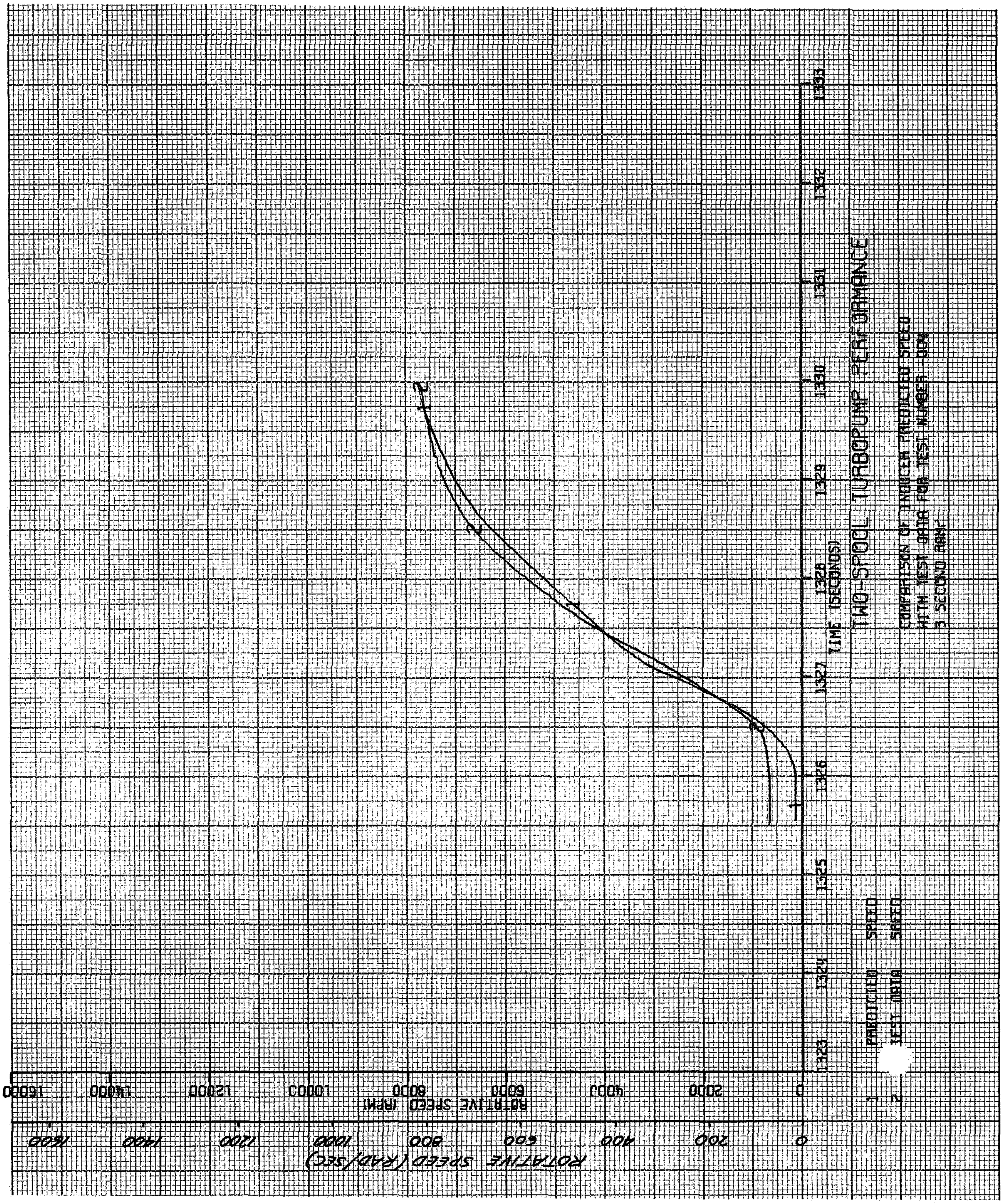

Figure 141. - Two-Spool Turbopump Performance, Inducer Predicted Speed vs Inducer Actual Speed, Test No. -004.

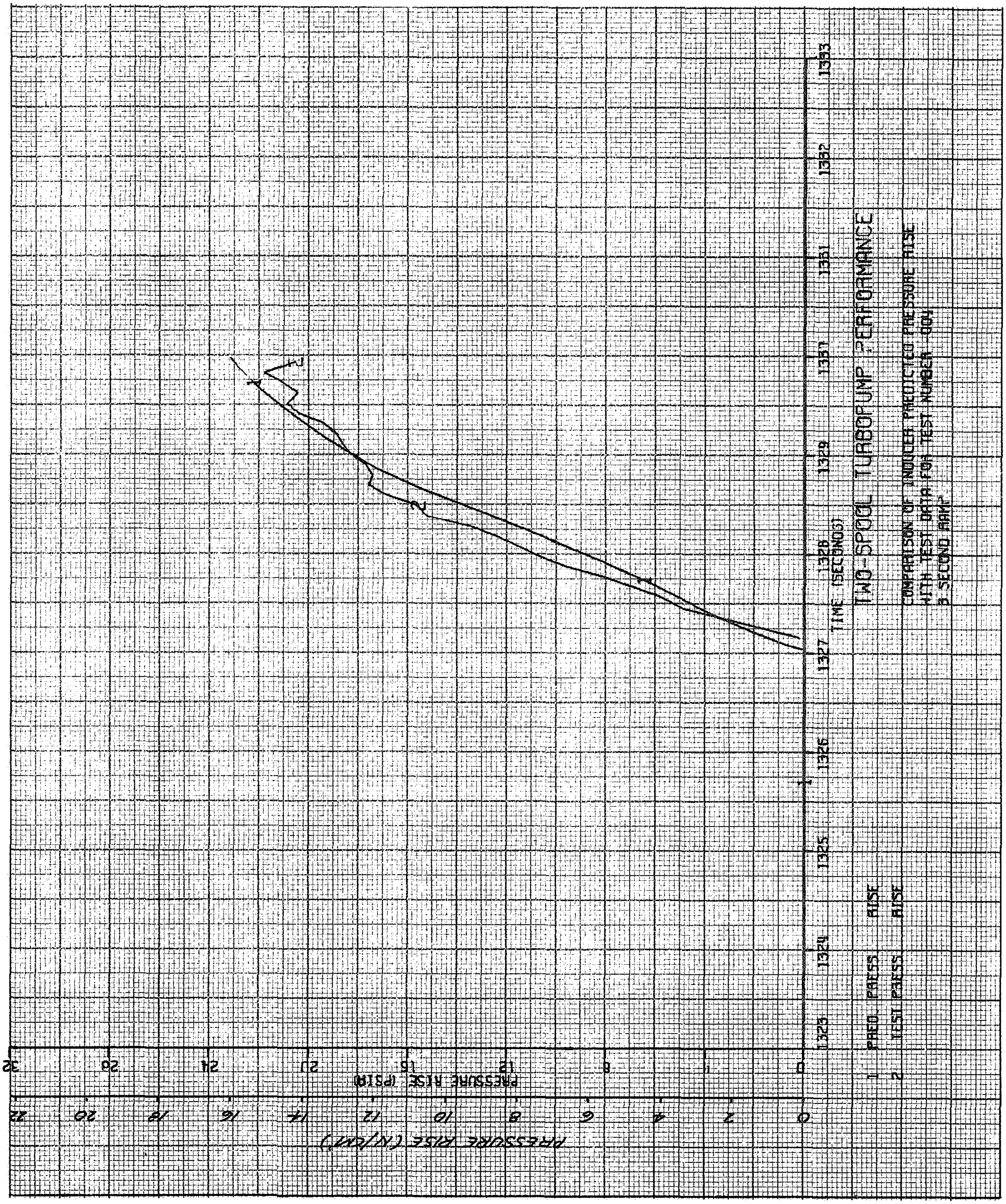

Figure 142. - Two-Spool Turbopump Performance, Inducer Predicted Pressure Rise vs Inducer Actual Pressure Rise, Test No. -004.

E. CONCLUSIONS

The turbopump testing verification of the computer model indicates that, at least for the type of unit tested, the model is quite adequate for predicting transient and steady-state operating conditions providing the following information is available:

1. Reasonably good characteristic curves for the inducer, pump, and turbines.
2. Accurate values for the rotating assembly polar moment of inertias.
3. Good representation of engine start ramp.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In addition to the specific conclusions relating to individual aspects of the program that are included as part of the test, the following over-all conclusions are pertinent.

1. The twin-spool turbopump exhibits an essentially non-cavitating performance both in pressure rise and flow range, while operating at zero NPSP and with moderate (to 30% by volume) vapor ingestion.

2. The flow coefficient range for low or essentially no system head loss at a zero tank NPSP exceeded the design requirements.

3. Based upon the transient start ramp response, the concept is applicable to either chemical or nuclear engine starting requirements.

4. There is no problem connected with the sensitivity of the inducer stage to reasonable variations in the turbine exhaust system area.

5. Twin-spool turbopump performance can be predicted and is a function of the accuracy of the predicted pump and turbine characteristics.

6. The accumulated running time (45 min at full speed and over 60 min total) demonstrates the basic mechanical concept to be a workable arrangement.

7. The Q/N range of the inducer is narrower than found in most boost pump concepts as a result of the power being extracted from the turbine drive gas (i.e., as main pump flow and power rise, the inducer sees almost the same percentage of increase in power). This allows the inducer to operate more closely to its best operating point for both efficiency and cavitation performance.

8. The twin-spool concept exhibited good hydraulic characteristics in both steady-state and transient applications. Based upon the results obtained to date, this system appears to be one of the more promising alternatives for two-phase hydrogen pumping.

B. RECOMMENDATIONS FOR FUTURE WORK

1. It is recommended that consideration be given to testing the twin-spool system with a hot gas turbine drive to permit its evaluation at conditions which more closely simulate an actual engine application.

2. If the twin-spool system were selected for an engine application it is recommended that start transients which simulate the relatively fast starter of gas generator (bleed cycle) chemical engines be investigated.

3. The inducer system exhibits a better two-phase pumping capability than predicted by the design; therefore, it is recommended that consideration be given to extending the experimental data to the lower hydrogen inlet temperatures (down to or including slush conditions).

4. It is recommended that the twin-spool concept be evaluated for cryogenic applications in both nuclear and chemical rocket systems where relatively short system chilldown times are desired. This effort probably would involve an analytical study followed by an experimental verification.

APPENDIX A

COMPUTER PROGRAM LISTING

APPENDIX A

```
C**** MOST OF THE LOGIC AND DETAILED PUMP AND TURBINE CALCULATIONS ARE
C**** CARRIED OUT IN THE MAIN PROGRAM
C
      REAL NM,NI,NIINT,NIFIN,IMA,II,NMINT,NPSPI,NPSHI,NPSNI,NPSPM,NPSHM,
     1NPSNM
      DIMENSION SHPPI(30),PRM(30),WTM(30),WTI(30),SHPTI(30),
     1P1(2),P2(2),W1(2),DATA1(75),
     2W2(2),SHP(30),CALC1(75,50),CALC2(12,50)
      DIMENSION T(25,30),SV(25,30),H(25,30),S(25,30),NUM(25),SSL(14),
     1TSL(14),P(25),AA(5,90),RHOX(90),B(9,8),K(13),L(4),XT(9,30),
     2YT(9,30),XP(4,30),YP(4,10,30),ZP(4,10),SONIC(25,30)
      COMMON IFLAG,JFLAG,KFLAG,JPRNT,JPLOT,TMINT,TMAX,XLINE,NIINT,FRI,
     1XLOSS,RM,RI,IMA,II,TPII,AI,AM,AME,D,DTIME,NFLAG
      EQUIVALENCE (TIME,DATA1(1)),(PSLI ,DATA1(2)),(PII,DATA1(3)),
     1(ZZZZ,DATA1(4)),(SVII,DATA1(5)),(WSLI ,DATA1(6)),(QII,DATA1(7)),
     2(WI,DATA1(8)),(PTII,DATA1(9)),(NI,DATA1(10)),(QNI,DATA1(11)),
     3(DPI,DATA1(12)),(PTIE,DATA1(13)),(PIE,DATA1(14)),(DHNI,DATA1(16)),
     3(DHI,DATA1(15)),
     4(NPSPI,DATA1(17)),(NPSHI,DATA1(18)),(NPSNI,DATA1(19)),
     5(EATPI,DATA1(20)),(SHPIF,DATA1(21)),(TORPI ,DATA1(22)),
     6(PMI,DATA1(23)),(PTMI,DATA1(24)),(TPMI,DATA1(25)),(SVMI,DATA1(26))
     7,(QMI,DATA1(27)),(WP,DATA1(28)),(NM,DATA1(29)),(QNM,DATA1(30)),
     8(DPM,DATA1(31)),(PTME,DATA1(32)),(PME,DATA1(33)),(DHM,DATA1(34)),
     9(DHNM,DATA1(35)),(NPSPM,DATA1(36)),(NPSHM,DATA1(37))
      EQUIVALENCE (NPSNM,DATA1(38)),(EATPM,DATA1(39)),(SHPPM,DATA1(40)),
     1(TORPM,DATA1(41)),(PTTII,DATA1(42)),(TTII,DATA1(43)),
     2(PTEI,DATA1(44)),(PRI,DATA1(45)),(WTIF,DATA1(46)),(FPI,DATA1(47)),
     3(DHTI,DATA1(48)),(COI,DATA1(49)),(UCOI,DATA1(50)),(EATTI,DATA1(51)
     4),(SHPTF,DATA1(52)),(TORTI,DATA1(53)),(PTTIM,DATA1(54)),
     5(TTIM,DATA1(55)),(PTTEM,DATA1(56)),(PRMF,DATA1(57)),(WTMF,DATA1(58
     6)),(FPM,DATA1(59)),(DHTM,DATA1(60)),(COM,DATA1(61)),
     7(UCOM,DATA1(62)),(EATTM,DATA1(63)),(SHPTM,DATA1(64)),
     8(TORTM,DATA1(65))
C
C**** CALL FILE TO READ IN HYDROGEN PROPERTIES DATA
C
      CALL FILE (T,SV,H,S,SONIC,NUM,SSL,TSL,P,AA,RHOX,B)
C
C**** INITIALIZE NCT=0,NCT IS THE COUNTER FOR PRINTING,WHEN NCT=50,A
C**** PAGE IS PRINTED
C
      NCT=0
      GO TO 52
   50 IF (NFLAG) 51,53,52
C
C**** NFLAG)0,LAST CASE
C
   51 STOP
C
C**** NFLAG,0,NEXT CASE REQUIRES NEW CHARACTERISTIC CURVES
C**** CALL INTAB TO READ IN CHARACTERISTIC CURVES
C
   52 CALL INTAB (IM,ID,IY,K,L,XT,YT,XP,YP,ZP)
C
C**** NFLAG=0,NEXT CASE REQUIRES CASE DATA ONLY
C**** CALL INPUT TO READ CASE DATA
C
   53 CALL INPUT (XT,YT,K,QNM,PATM ,IM,ID,IY)
      CT=2.*32.174*778.16
```

```
C
C**** COMPUTE SUCTION LINE CONSTANT
C
      R=FRI*XLINE/(2.*32.174*D)
C
C**** CALL TABIN TO INITIALIZE TURBINE INLET TEMPERATURE
C
      CALL TABIN (TMINT,6,K,XT,YT,TTIM,J,PARMX,PARMN)
      ITAB=12
      PAR1=TMINT
      IF (J-1) 55,55,850
   55 GO TO (60,66),IFLAG
C
C**** IFLAG=1,TURBINE INLET PRESSURE INPUT CASE
C
   60 CALL TABIN (TMINT,7,K,XT,YT,PTTIM,J,PARMX,PARMN)
      ITAB=13
      PAR1=TMINT
      IF (J-1) 65,65,850
   65 GAMM=GAMMA(TTIM,PTTIM)
      CPM=CP(TTIM,PTTIM)
      GO TO 68
C
C**** IFLAG=2,MAIN SHAFT SPEED INPUT CASE,INITIALIZE GAMM AND CPM AT
C**** 100 PSIA
C
   66 GAMM=GAMMA(TTIM,100.)
      CPM=CP(TTIM,100.)
C
C**** CALL TABIN TO INITIALIZE MAIN SHAFT SPEED
C
   68 CALL TABIN (TMINT,8,K,XT,YT,NM,J,PARMX,PARMN)
      ITAB=14
      PAR1=TMINT
      IF (J-1) 70,70,850
C
C**** SET TIME=INITIAL TIME,TMINT
C
   70 TIME=TMINT
C
C**** SET INDUCER SPEE=INITIAL ESTIMATE NIINT
C
      NI=NIINT
C
C**** SET TIME POINT COUNTER,JT=1
C
      JT=1
C
C**** SET PRINT INTERVAL COUNTER,JP=0
C
      JP=0
C
C**** SET INITIAL GUESS OF TURBINE EXHAUST TEMPERATURE=0.75 INLET TEMP.
C
      TTEG=0.75*TTIM
      IPR=1
      JPR=1
      IERAN=0
C
C**** CALL TABIN TO INITIALIZE TANK PRESSURE
```

```
C
      CALL TABIN (TMINT,9,K,XT,YT,PTK,J,PARMX,PARMN)
      ITAB=18
      PAR1=TMINT
      IF (J-1) 75,75,850
C
C**** SET ALL SUCTION LINE PRESSURES INITIALLY EQUAL TO TANK PRESSURE
C
   75 P1(1)=PTK
      PSLI=PTK
      P1(2)=PTK
      P2(1)=PTK
      PII=PTK
C
C**** SET MAIN PUMP INLET TEMPERATURE AND PRESSURE INITIALLY EQUAL TO
C**** INDUCER INLET CONDITIONS
C
      TPMI=TPII
      PMI=PTK
      ZZZZ=TPII
      MCT=0
      IPAGE=6
      IPS=0
      GO TO 110
C
C**** RETURN POINT FOR SUCCESSIVE TIME POINTS OF TRANSIENT CASES
C
   80 GO TO (85,95),JFLAG
C
C**** JFLAG=1,WATERHAMMER SOLUTION INCLUDED,DETERMINE SUCTION LINE SONIC
C**** VELOCITY
C
   85 CALL HPROP (PII,TPII,SONIC,T,1,5,NUM,P,B,SOV,J,PARMN,PARMX)
      IHPR=1
      PAR1=PII
      PAR2=TPII
      IF (J-1) 86,86,865
C
C**** COMPUTE TIME INCREMENT
C
   86 DTIME=XLINE/SOV
C
C**** SET INITIAL SUCTION LINE CONDITIONS EQUAL TO FINAL SUCTION LINE
C**** CONDITIONS FROM PREVIOUS TIME POINT
C
      W2(1)=WP
      P2(1)=PII
      W1(1)=W1(2)
C
C**** COMPUTE NEW TIME
C
   95 TIME=TIME+DTIME
C
C**** SET INDUCER SPEED EQUAL TO NEW INDUCER SPEED COMPUTED FROM ACCEL.
C**** RELATION
C
      NI=NIINT
C
C**** INCREMENT PRINT AND TIME POINT COUNTERS
```

```
C
      JP=JP+1
      JT=JT+1
      JPR=2
      IPR=2
C
C**** CALL TABIN FOR NEW TANK PRESSURE
C
      CALL TABIN (TIME,9,K,XT,YT,PTK,J,PARMX,PARMN)
      ITAB=19
      PAR1=TIME
      IF (J-1) 99,99,850
C
C**** CALL TABIN FOR NEW TURBINE INLET TEMPERATURE
C
   99 CALL TABIN (TIME,6,K,XT,YT,TTIM,J,PARMX,PARMN)
      ITAB=15
      PAR1=TIME
      IF (J-1) 101,101,850
  101 GO TO (105,106),IFLAG
C
C**** IFLAG=1,TURBINE INLET PRESSURE CASE
C
  105 CALL TABIN (TIME,7,K,XT,YT,PTTIM,J,PARMX,PARMN)
      ITAB=16
      PAR1=TIME
      IF (J-1) 107,107,850
C
C**** COMPUTE GAMM FOR NEW TURBINE INLET CONDITIONS
C
  107 GAMM=GAMMA(TTIM,PTTIM)
C
C**** COMPUTE CPM  FOR NEW TURBINE INLET CONDITIONS
C
      CPM=CP(TTIM,PTTIM)
C
C**** SET MAIN SHAFT SPEED EQUAL NEW SPEED COMPUTED FROM ACCEL. RELATION
C
      NM=NMINT
      GO TO 110
C
C**** IFLAG=2,MAIN SHAFT SPEED INPUT CASE,SAVE MAIN SHAFT SPEED FROM
C**** PREVIOUS TIME POINT
C
  106 NMINT=NM
C
C**** CALL TABIN FOR NEW MAIN SHAFT SPEED
C
      CALL TABIN (TIME,8,K,XT,YT,NM,J,PARMX,PARMN)
      ITAB=17
      PAR1=TIME
      IF (J-1) 110,110,850
C
C**** ITER2 IS THE MAIN SHAFT SPEED CORRECTION LOOP ITERATION COUNTER
C
  110 ITER2=0
C
C**** ITER6 IS THE MAIN TURBINE PRESSURE RATIO CORRECTION LOOP ITERATION
C**** COUNTER
C
```

```
      ITER6=1
C
C**** SAVE MAIN TURBINE PRESSURE RATIO FROM PREVIOUS TIME POINT
C
      PRM(1)=PRMF
      IF (JT-1) 113,113,112
  112 P1(1)=PSLI
C
C**** COMPUTE SUCTION LINE INLET STATIC PRESSURE
C
      PSLI=PTK-(WSLI/AI)**2*144.*SVII/2./32.174
C
C**** COMPUTE INDUCER INLET PRESSURE
C
      PII=PSLI-0.000174954*FRI*XLINE*SVII*WP**2/D**5
C
C**** ITER4 IS THE INDUCER SHAFT SPEED CORRECTION LOOP ITERATION COUNTER
C
  113 ITER4=1
C
C**** DETERMINE VAPOR PRESSURE AT THE INDUCER INLET
C
      PVPII=VPFUN(TPII)
C
C**** COMPARE INDUCER INLET PRESSURE WITH INDUCER INLET VAPOR PRESSURE
C
      IF (PII-PVPII) 111,111,115
C
C**** INDUCER INLET PRESSURE IS LESS THAN OR EQUAL TO VAPOR PRESSURE,
C**** USE SATURATED LIQUID SPECIFIC VOLUME
C
  111 SVII=SVSL(TPII,B)
      GO TO 120
C
C**** CALL HPROP FOR INDUCER INLET SPECIFIC VOLUME
C
  115 CALL HPROP (PII,TPII,SV,T,1,2,NUM,P,B,SVII,J,PARMN,PARMX)
      IHPR=2
      PAR1=PII
      PAR2=TPII
      IF (J-1) 120,120,865
C
C**** RETURN POINT FOR MAIN SHAFT SPEED CORRECTION LOOP,INCREMENT
C**** ITERATION COUNTER
C
  120 ITER2=ITER2+1
C
C**** COMPUTE MAIN PUMP INLET VOLUMETRIC FLOW RATE
C
      QMI=QNM*NM
C
C**** COMPUTE MAIN TURBINE MEAN BLADE SPEED
C
      UM=2.*3.14159*NM*RM/12./60.
C
C**** ITER1 IS THE PUMP INLET PRESSURE CORRECTION LOOP ITERATION COUNTER
C
      ITER1=0
  125 ITER1=ITER1+1
```

```
C
C**** DETERMINE PUMP INLET VAPOR PRESSURE
C
      PVPMI=VPFUN(TPMI)
C
C**** COMPARE PUMP INLET PRESSURE WITH VAPOR PRESSURE
C
      IF (PMI-PVPMI) 121,121,122
C
C**** PUMP INLET PRESSURE IS LESS THAN OR EQUAL TO VAPOR PRESSURE,
C**** USE SATURATED LIQUID SPECIFIC VOLUME
C
  121 SVMI=SVSL(TPMI,B)
      GO TO 123
C
C**** PUMP INLET PRESSURE IS GREATER THAN VAPOR PRESSURE,CALL HPROP FOR
C**** PUMP INLET SPECIFIC VOLUME
C
  122 CALL HPROP (PMI,TPMI,SV,T,1,2,NUM,P,B,SVMI,J,PARMN,PARMX)
      IHPR=3
      PAR1=PMI
      PAR2=TPII
      IF (J-1) 123,123,865
C
C**** COMPUTE PUMP WEIGHT FLOW RATE
C
  123 WP=GMI/(SVMI*60.*7.4806)
      WSLI=WP
C
C**** TEST FOR FIRST TIME POINT
C
      IF (JT-1) 124,124,131
C
C**** IF FIRST TIME POINT AND FIRST PASS,IPS=0,RETURN TO STATEMENT 112
C**** WITH SUCTION LINE FLOW RATE TO COMPUTE SUCTION LINE PRESSURE
C
  124 IF (IPS) 128,127,128
  127 IPS=1
      GO TO 112
C
C**** CONVERGENCE TEST FOR SUCTION LINE INLET PRESSURE
C
  128 IF (ABS(1.-PSLI/P1(1))-0.001) 131,131,112
  131 P1(1)=PSLI
C
C**** SET INDUCER WEIGHT FLOW RATE EQUAL PUMP WEIGHT FLOW RATE
C
      WI=WP
      GO TO (126,136),JFLAG
C
C**** JFLAG=1,WATERHAMMER SOLUTION USED,CHECK FIRST TIME POINT
C
  126 IF (JT-1) 130,130,135
C
C**** JT=1,FIRST TIME POINT,SAVE WP IN W1(2) FOR WATERHAMMER SOLUTION
C
  130 W1(2)=WP
      GO TO 136
C
C**** JT IS GREATER THAN 1,SET SUCTION LINE DISCHARGE FLOW RATE EQUAL
```

```
C**** PUMP FLOW RATE
C
  135 W2(2)=WP
      P1(2)=PSLI
C
C**** CALL INLET FOR SUCTION LINE WATERHAMMER SOLUTION,THE FINITE
C**** DIFFERENCE SOLUTION IS FOR A GIVEN LINE INLET PRESSURE AND
C**** DISCHARGE FLOW RATE WITH INLET FLOW RATE AND DISCHARGE PRESSURE
C**** GIVEN BY THE SOLUTION
C
      CALL INLET (CTIME,W1,W2,P1,P2,SCV,SVII,AI,R)
      WSLI=W1(2)
      PII=P2(2)
C
C**** COMPUTE INDUCER INLET VOLUMETRIC FLOW RATE
C
  136 QII=WP*SVII*60.*7.4806
C
C**** COMPUTE INDUCER INLET TOTAL PRESSURE
C
      PTII=PII+(WP/AI)**2*144.*SVII/2./32.174
C
C**** COMPUTE INDUCER NET POSITIVE SUCTION PRESSURE
C
      NPSPI=PTII-PVPII
C
C**** COMPUTE INDUCER NET POSITIVE SUCTION HEAD
C
      NPSHI=144.*NPSPI*SVII
C
C**** COMPUTE INDUCER NORMALIZED SUCTION HEAD
C
      NPSNI=NPSHI/NI**2
C
C**** CALL SHPIN FOR INDUCER SPEED POWER TABLE GENERATION
C
      CALL SHPIN (WF,QII,NPSNI,K,L,ZP,XP,YP,XT,YT)
      GO TO 145
C
C**** RETURN POINT FOR INDUCER SPEED CORRECTION LOOP,INCREMENT COUNTER
C
  140 ITER4=ITER4+1
C
C**** RESET MAIN TURBINE PRESSURE RATIO
C
      PRM(1)=PRM(ITER6)
C
C**** RESET MAIN SHAFT SPEED ITERATION COUNTER
C
      ITER2=1
      JPR=2
C
C**** RESET MAIN TURBINE PRESSURE RATIO ITERATION COUNTER
C
      ITER6=1
C
C**** COMPUTE INDUCER NORMALIZED FLOW RATE
C
  145 QNI=QII/NI
```

```
C
C**** COMPUTE INDUCER TURBINE MEAN BLADE SPEED
C
      UI=2.*3.14159*NI*RI/12./60.
      ITAB=7
C
C**** CALL TABP FOR INDUCER NORMALIZED HEAD RISE
C
      CALL TABP (NPSNI,QNI,3,K,L,ZP,XP,YP,DHNI,J,PARMN,PARMX)
      PAR1=QNI
      IF (J-2) 150,860,151
  150 ITAB=8
C
C**** CALL TABP FOR INDUCER EFFICIENCY
C
      CALL TABP (NPSNI,QNI,4,K,L,ZP,XP,YP,EATPI,J,PARMN,PARMX)
      PAR1=QNI
      IF (J-1) 155,155,860
C
C**** INDUCER NORMALIZED FLOW RATE IS GREATER THAN MAXIMUM TABULATED
C**** VALUE,SET HEAD RISE EQUAL ZERO AND EFF. EQUAL 1.
C
  151 DHNI=0.0
      EATPI=1.
C
C**** COMPUTE INDUCER HEAD RISE
C
  155 DHI=DHNI*NI**2
C
C**** COMPUTE INDUCER PRESSURE RISE
C
      DPI=DHI/(144.*SVII)
C
C**** COMPUTE INDUCER POWER
C
      SHPPI(ITER4)=WP*DHI/550./EATPI
C
C**** COMPUTE INDUCER TORQUE
C
      TORPI=SHPPI(ITER4)*33000./(2.*3.14159*NI)
C
C**** COMPUTE PUMP INLET TOTAL PRESSURE
C
      PTMI=PTII+DPI
C
C**** SET INDUCER DISCHARGE TOTAL PRESSURE EQUAL PUMP INLET TOTAL
C**** PRESSURE
C
      PTIE=PTMI
C
C**** SAVE PUMP INLET PRESSURE FOR SUCCESSIVE ITERATIONS
C
      PMIF=PMI
C
C**** COMPUTE PUMP INLET STATIC PRESSURE
C
      PMI=PTMI-(WP/AM)**2*144.*SVMI/2./32.174
C
C**** SET INDUCER DISCHARGE STATIC PRESSURE EQUAL PUMP INLET STATIC
C**** PRESSURE
```

```
C
      PIE=PMI
      IF (JT-1)156,154,156
C
C**** CONVERGENCE TEST FOR PUMP INLET PRESSURE,FIRST TIME POINT ONLY
C
  154 IF (ABS(1.-PMI/PMIF)-.001) 156,156,125
C
C**** COMPUTE MAIN PUMP NET POSITIVE SUCTION PRESSURE
C
  156 NPSPM=PTMI-PVPMI
C
C**** COMPUTE MAIN PUMP NET POSITIVE SUCTION HEAD
C
      NPSHM=144.*NPSPM*SVMI
C
C**** COMPUTE MAIN PUMP NORMALIZED SUCTION HEAD
C
      NPSNM=NPSHM/NM**2
      IPS=0
      ITAB=5
C
C**** CALL TABP FOR MAIN PUMP NORMALIZED HEAD RISE
C
      CALL TABP (NPSNM,QNM,1,K,L,ZP,XP,YP,DHNM,J,PARMN,PARMX)
      PAR1=QNM
      IF (J-1) 160,160,860
  160 ITAB=6
C
C**** CALL TABP FOR MAIN PUMP EFFICIENCY
C
      CALL TABP (NPSNM,QNM,2,K,L,ZP,XP,YP,EATPM,J,PARMN,PARMX)
      PAR1=QNM
      IF (J-1) 165,165,860
C
C**** COMPUTE MAIN PUMP HEAD RISE
C
  165 DHM=DHNM*NM**2
C
C**** COMPUTE MAIN PUMP PRESSURE RISE
C
      DPM=DHM/(144.*SVMI)
C
C**** COMPUTE MAIN PUMP POWER
C
      SHPPM=WP*DHM/550./EATPM
C
C**** COMPUTE MAIN PUMP TORQUE
C
      TORPM=33000.*SHPPM/(2.*3.14159*NM)
C
C**** COMPUTE MAIN PUMP DISCHARGE TOTAL PRESSURE
C
      PTME=PTMI+DPM
C
C**** COMPUTE MAIN PUMP DISCHARGE STATIC PRESSURE
C
      PME=PTME-(WP/AME)**2*144.*SVMI/2./32.174
      IF (IPR-1) 180,180,205
```

```
C
C**** IF FIRST PASS,CALL PRATO TO INITIALIZE MAIN TURBINE PRESSURE RATIO
C
  180 CALL PRATO (SHPPM,TTIM,PATM ,UM,GAMM,CPM,CT,XT,YT,K    ,PRM(1),PARM
     1N,PARMX,PAR1,J)
      IPR=2
      ITAB=10
      IF (J-1) 195,195,855
C
C**** RETURN POINT FOR MAIN TURBINE PRESSURE RATIO CORRECTION LOOP,
C**** INCREMENT COUNTER
C
  190 ITER6=ITER6+1
      JTEMP=0
  195 ITER5=0
  200 ITER5=ITER5+1
  205 ITAB=1
C
C**** CALL TABIN FOR MAIN TURBINE FLOW PARAMETER
C
      CALL TABIN (PRM(ITER6),ITAB,K,XT,YT,FPM,J,PARMX,PARMN)
      PAR1=PRM(ITER6)
      IF (J-1) 210,210,850
C
C**** COMPUTE MAIN TURBINE CO
C
  210 CCM=SQRT(CT*CPM*TTIM*(1.-(1./PRM(ITER6))**((GAMM-1.)/GAMM)))
C
C**** COMPUTE MAIN TURBINE VELOCITY RATIO
C
      UCCM=UM/CCM
      ITAB=2
C
C**** CALL TABIN FOR MAIN TURBINE EFFICIENCY
C
      CALL TABIN (UCCM,ITAB,K,XT,YT,EATTM,J,PARMX,PARMN)
      PAR1=UCCM
      IF (J-1) 215,215,850
C
C**** COMPUTE MAIN TURBINE ENTHALPY DROP
C
  215 DHTM=EATTM*CCM**2/CT
      GO TO (220,250),IFLAG
C
C**** IFLAG=1,TURBINE INLET PRESSURE OPTION,COMPUTE MAIN TURBINE FLOW
C**** RATE
C
  220 WTM(ITER6)=FPM*PTTIM/SQRT(TTIM)
C
C**** COMPUTE MAIN TURBINE POWER
C
      SHPTM=778.16*WTM(ITER6)*DHTM/550.
C
C**** COMPUTE MAIN TURBINE TORQUE
C
      TORTM=33000.*SHPTM/(2.*3.14159*NM)
C
C**** CHECK FIRST TIME POINT
C
      IF (JT-1) 225,225,230
```

```
C
C**** FIRST TIME POINT,SAVE MAIN SHAFT SPEED FOR SUCCESSIVE ITERATIONS
C**** UNTIL MAIN TURBINE POWER EQUALS PUMP POWER
C
  225 NMINT=NM
C
C**** CONVERGENCE TEST FOR MAIN SHAFT POWER
C
      IF (ABS(1.-SHPTM/SHPPM)-.001) 270,270,226
C
C**** NO POWER BALANCE,CHECK ITERATION COUNTER
C
  226 IF (ITER2-30) 227,900,900
C
C**** LESS THAN THIRTY ITERATIONS,CORRECT MAIN SHAFT SPEED
C
  227 NM=NM*(SHPTM/SHPPM)**0.333333
      GO TO 120
C
C**** TIME IS GREATER THAN FIRST TIME POINT,COMPUTE NEW SPEED FROM
C**** ACCELERATION RELATION
C
  230 NMINT=NM+720.*DTIME*(TORTM-TORPM)/(2.*3.14159*IMA)
      GO TO 270
C
C**** IFLAG=2,MAIN SHAFT SPEED OPTION,CHECK FIRST TIME POINT
C
  250 IF (JT-1) 255,255,260
C
C**** FIRST TIME POINT,SET TURBINE POWER EQUAL PUMP POWER
C
  255 SHPTM=SHPPM
C
C**** SET MAIN TURBINE TORQUE EQUAL PUMP TORQUE
C
      TORTM=TORPM
      GO TO 265
C
C**** TIME IS GREATER THAN FIRST TIME POINT,COMPUTE NEW TORQUE FROM
C**** ACCELERATION RELATION
C
  260 TORTM=TORPM+2.*3.14159*IMA*(NM-NMINT)/(720.*DTIME)
C
C**** COMPUTE MAIN TURBINE POWER
C
      SHPTM=2.*3.14159*NM*TORTM/33000.
C
C**** COMPUTE MAIN TURBINE FLOW RATE
C
  265 WTM(ITER6)=550.*SHPTM/(778.16*DHTM)
C
C**** COMPUTE MAIN TURBINE INLET TOTAL PRESSURE
C
      PTTIM=WTM(ITER6)*SQRT(TTIM)/FPM
      GAMM=GAMMA(TTIM,PTTIM)
      CPM=CP(TTIM,PTTIM)
  270 ITER2=0
C
C**** COMPUTE MAIN TURBINE EXHAUST TOTAL PRESSURE
```

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C
      PTTEM=PTTIM/PRM(ITER6)
C
C**** SET INDUCER TURBINE INLET TOTAL PRESSURE EQUAL MAIN TURBINE
C**** EXHAUST TOTAL PRESSURE
C
      PTTII=PTTEM
      GO TO 320
C
C**** RETURN POINT FOR INDUCER TURBINE EXHAUST PRESSURE CALCULATION
C
  310 TTEG=TTEI
      JTEMP=1
C
C**** COMPUTE INDUCER TURBINE EXHAUST PRESSURE
C
  320 PTEI=(PATM+SQRT(PATM**2+4.*XLOSS*WTM(ITER6)**2*TTEG))/2.
C
C**** COMPUTE INDUCER TURBINE PRESSURE RATIO
C
      PRI=PTTII/PTEI
C
C**** CHECK INDUCER TURBINE PRESSURE RATIO LESS THAN 1.
C
      IF (PRI-1.) 350,350,360
C
C**** INDUCER TURBINE PRESSURE RATIO IS LESS THAN 1.,REDUCE MAIN TURBINE
C**** PRESSURE RATIO
C
  350 PRM(ITER6)=0.75*PRM(ITER6)+0.25
C
C**** CHECK ITERATION COUNTER,IF LESS THAN 30,RETURN WITH REDUCED
C**** PRESSURE RATIO
C
      IF (ITER5-30) 200,900,900
  360 ITAB=3
C
C**** CALL TABIN FOR INDUCER TURBINE FLOW PARAMETER
C
      CALL TABIN (PRI,ITAB,K,XT,YT,FPI,J,PARMX,PARMN)
      PAR1=PRI
      IF (J-1) 370,370,850
C
C**** COMPUTE MAIN TURBINE EXHAUST TOTAL TEMPERATURE
C
  370 TTEM=TTIM-DHTM/CPM
C
C**** SET INDUCER TURBINE INLET TOTAL TEMPERATURE EQUAL MAIN TURBINE
C**** EXHAUST TOTAL TEMPERATURE
C
      TTII=TTEM
C
C**** COMPUTE INDUCER TURBINE FLOW RATE
C
      WTI(ITER6)=FPI*PTTII/SQRT(TTII)
C
C**** CONVERGENCE TEST FOR TURBINE FLOW RATE,450 IF MAIN TURBINE AND
C**** INDUCER TURBINE FLOW RATES ARE SUFFICIENTLY CLOSE
C
      IF (ABS(1.-WTM(ITER6)/WTI(ITER6))-.001) 450,450,400
```

```
C
C**** FLOW RATE DIFFERENCE EXCEEDS TOLERANCE,CHECK FIRST PASS THROUGH
C**** MAIN TURBINE PRESSURE RATIO CORRECTION LOOP
C
  400 IF (ITER6-1) 420,420,430
C
C**** FIRST PASS IN LOOP CHECK FIRST PASS THROUGH PROGRAM
C
  420 IF (JPR-1) 421,421,445
C
C**** FIRST PASS THROUGH PROGRAM,CORRECT MAIN TURBINE PRESSURE RATIO
C**** WITH PRATC FOR NEW BACK PRESSURE
C
  421 CALL PRATC (SHPPM,TT1M,PTTEM,UM,GAMM,CPM,CT,XT,YT,K    ,PRM(2),PARM
     1N,PARMX,PAR1,J)
      ITAB=11
      IF (J-1) 190,190,855
C
C**** NOT THE FIRST PASS THROUGH PRESSURE RATIO CORRECTION LOOP,IF
C**** ITERATION COUNTER IS LESS THAN 30 CORRECT PRESSURE RATIO
C
  430 IF (ITER6-30) 440,900,900
  440 IF (JTEMP) 441,441,445
C
C**** JTEMP=0,PRESSURE RATIOS AND FLOW RATES OF BOTH TURBINES HAVE BEEN
C**** CHANGED,COMPUTE NEW SLOPES
C
  441 SLOP1=(WTM(ITER6)-WTM(ITER6-1))/(PRM(ITER6)-PRM(ITER6-1))
C
C**** SLOP1 IS THE RATE OF CHANGE OF MAIN TURBINE FLOW RATE WITH MAIN
C**** TURBINE PRESSURE RATIO
C
C
C**** SLOP2 IS THE RATE OF CHANGE OF INDUCER TURBINE FLOW RATE WITH MAIN
C**** TURBINE PRESSURE RATIO
C
      SLOP2=(WTI(ITER6)-WTI(ITER6-1))/(PRM(ITER6)-PRM(ITER6-1))
C
C**** CORRECT MAIN TURBINE PRESSURE RATIO
C
  445 PRM(ITER6+1)=PRM(ITER6)+(WTI(ITER6)-WTM(ITER6))/(SLOP1-SLOP2)
      IF (PRM(ITER6+1)-1.0) 446,446,190
  446 PRM(ITER6+1)=1.01
      GO TO 190
  450 GAMI=GAMMA(TTII,PTTII)
      CPI=CP(TTII,PTTII)
C
C**** COMPUTE INDUCER TURBINE ENTHALPY DROP
C
      DHTII=CPI*TTII*(1.-(1./PRI)**((GAMI-1.)/GAMI))
C
C**** COMPUTE INDUCER TURBINE CO
C
      COI=SQRT(CT*DHTII)
C
C**** COMPUTE INDUCER TURBINE VELOCITY RATIO
C
      UCOI=UI/COI
      ITAB=4
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C
C**** CALL TABIN FOR INDUCER TURBINE EFFICIENCY
C
      CALL TABIN (UCOI,ITAB,K,XT,YT,EATTI,J,PARMX,PARMN)
      PAR1=UCOI
      IF (J-1) 500,500,850
C
C**** COMPUTE INDUCER TURBINE ENTHALPY DROP
C
  500 DHTI=EATTI*DHTII
C
C**** COMPUTE INDUCER TURBINE EXHAUST TEMPERATURE
C
      TTEI=TTII-DHTI/CPI
C
C**** CONVERGENCE TEST FOR INDUCER TURBINE EXHAUST TEMPERATURE
C
      IF (ABS(1.-TTEI/TTEG)-.001) 510,510,310
C
C**** COMPUTE INDUCER TURBINE POWER
C
  510 SHPTI(ITER4)=WTI(ITER6)*DHTI*778.16/550.
C
C**** COMPUTE INDUCER TURBINE TORQUE
C
      TORTI=33000.*SHPTI(ITER4)/(2.*3.14159*NI)
      IF (JT-1) 550,550,650
  550 NIINT=NI
C
C**** CONVERGENCE TEST ON  INDUCER SHAFT POWER FOR STEADY STATE POINTS
C
      IF (ABS(1.-SHPPI(ITER4)/SHPTI(ITER4))-.001) 700,560,560
C
C**** THE DIFFERENCE BETWEEN INDUCER TURBINE AND INDUCER POWER EXCEEDS
C**** TOLERANCE,TEST FOR FIRST PASS
C
  560 IF (ITER4-1) 570,570,565
C
C**** NOT THE FIRST PASS,CHECK FOR 30 ITERATIONS
C
  565 IF (ITER4-30) 580,900,900
C
C**** FIRST PASS,AVERAGE INDUCER AND INDUCER TURBINE POWER TO DETERMINE
C**** NEW INDUCER SPEED
C
  570 SHPAV=(SHPPI(1)+SHPTI(1))/2.
      NIFIN=NI
      ITAB=9
C
C**** CALL TABIN FOR NEW INDUCER SPEED
C
      CALL TABIN (SHPAV,5,K,XT,YT,NI,J,PARMX,PARMN)
      PAR1=SHPAV
      IF (J-1) 140,140,850
C
C**** FOR OTHER THAN THE FIRST ITERATION,COMPUTE RATE OF CHANGE OF
C**** INDUCER POWER WITH SPEED,SLOP3
C
  580 SLOP3=(SHPPI(ITER4)-SHPPI(ITER4-1))/(NI-NIFIN)
C
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C**** COMPUTE RATE OF CHANGE OF INDUCER TURBINE POWER WITH SPEED
C
      SLOP4=(SHPTI(ITER4)-SHPTI(ITER4-1))/(NI-NIFIN)
      NIFIN=NI
C
C**** CORRECT INDUCER SPEED TO OBTAIN BALANCE BETWEEN INDUCER AND
C**** INDUCER,TURBINE POWER
C
      NI=NI+(SHPTI(ITER4)-SHPPI(ITER4))/(SLOP3-SLOP4)
      GO TO 140
C
C**** NOT A STEADY STATE POINT,COMPUTE NEW INDUCER SPEED BASED ON
C**** ACCELERATION RELATION
C
  650 NIINT=NI+720.*DTIME*(TORTI-TORPI)/(2.*3.14159*II)
C
C**** CASE OR TIME POINT COMPLETE,SAVE INTERMEDIATE VALUES FOR PRINTING
C
  700 PRMF=PRM(ITER6)
      WTMF=WTM(ITER6)
      WTIF=WTI(ITER6)
      SHPIF=SHPPI(ITER4)
      SHPTF=SHPTI(ITER4)
C
C**** TEST FOR STEADY STATE OR TRANSIENT CASE
C
      GO TO (710,720),KFLAG
C
C**** KFLAG=1,STEADY STATE CASE,CALL OUT3 FOR OUTPUT
C
  710 CALL OUT3 (DATA1,IM,ID,IY,IPAGE)
      GO TO 50
C
C**** KFLAG=2,TRANSIENT CASE,COMPARE TIME WITH MAXIMUM TIME
C
  720 IF (TIME-TMAX) 735,760,760
C
C**** TIME IS LESS THAN MAXIMUM TIME,CHECK FOR FIRST TIME POINT
C
  735 IF (JT-1) 750,750,740
C
C**** NOT FIRST TIME POINT,CHECK PRINT INTERVAL
C
  740 IF (JPRNT-JP) 745,745,790
C
C**** THIS TIME POINT TO BE PRINTED,RESET COUNTER TO 0
C
  745 JP=0
C
C**** INDEX PRINT COUNTER
C
  750 NCT=NCT+1
C
C**** SAVE COMPUTED DATA FOR PRINTING IN DATA1
C
      DO 755 I=1,75
  755 DATC1(I,NCT)=DATA1(I)
C
C**** CHECK FOR PLOTTING
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C
      IF (JPLOT-1) 758,757,757
C
C**** JPLOT IS GREATER THAN 0,CALL PLOT SUBROUTINE
C
  757 CALL PLOT (64,DATA1,IBRAN)
      IBRAN=1
C
C**** CHECK FOR 50 TIME POINTS SAVED FOR PRINTING
C
  758 IF (NCT-50) 80,756,756
C
C**** 50 TIME POINTS HAVE BEEN SAVED FOR PRINTING,CALL OUT1 FOR OUTPUT
C
  756 CALL OUT1 (CALC1,NCT,IM,ID,IY,IPAGE)
      NCT=0
      GO TO 80
C
C**** THIS TIME POINT NCT TO BE PRINTED,TEST FOR WATERHAMMER SOLUTION
C
  790 GO TO (791,80),JFLAG
C
C**** JFLAG=1,WATERHAMMER SOLUTION HAS BEEN INCLUDED,SAVE SUCTION
C**** LINE AND INDUCER DATA FOR PRINTING
C
  791 MCT=MCT+1
      DO 795 I=1,12
  795 CALC2(I,MCT)=DATA1(I)
      IF (JPLOT-1) 820,810,820
  810 CALL PLOT (64,DATA1,IBRAN)
      IBRAN=1
C
C**** CHECK FOR 50 INTERMEDIATE TIME POINTS COMPUTED
C
  820 IF (MCT-50) 80,796,796
C
C**** 50 INTERMEDIATE TIME POINTS COMPUTED,CALL OUT2 FOR INTERMEDIATE
C**** OUTPUT
C
  796 CALL OUT2 (CALC2,MCT,IM,ID,IY,IPAGE)
      MCT=0
      GO TO 80
  850 IDIAG=1
      GO TO 910
  855 IDIAG=2
      GO TO 910
  860 IDIAG=3
      GO TO 910
  865 IDIAG=4
      GO TO 910
  900 IDIAG=5
C
C**** CALL DIAG FOR DIAGNOSTIC MESSAGES
C
  910 CALL DIAG (IDIAG,J,ITAB,IHPR,ITER1,ITER2,ITER4,ITER5,ITER6,PAR1,
     1PAR2,PARMN,PARMX)
C
C**** AFTER DIAGNOSTIC MESSAGE,PRINT DATA SAVED FROM PREVIOUS TIME
C**** POINTS INCLUDING INCOMPLETE LAST CASE
C
```

```
      GO TO (700,765),KFLAG
  765 IF(NCT) 50,50,760
  760 NCT=NCT+1
      DO 770 I=1,75
  770 CALC1(I,NCT)=DATA1(I)
      IF (JPLOT-1) 773,765,765
  765 CALL PLOT (64,DATA1,IBRAN)
      IBRAN=1
  773 CALL OUT1 (CALC1,NCT,IM,ID,IY,IPAGE)
      NCT=0
      IF (MCT) 50,50,775
  775 CALL OUT2 (CALC2,MCT,IM,ID,IY,IPAGE)
      GO TO 50
      END
```

APPENDIX A

```
C**** SUBROUTINE FILE ****
C**** THIS SUBROUTINE READS IN THE HYDROGEN PROPERTIES DATA TO BE USED
C**** IN SUBROUTINE HPROP
C
      SUBROUTINE FILE (T,SV,H,S,SONIC,NUM,SSL,TSL,P,AA,RHOX,B)
      REAL NIINT,NC(4),IMA,II
      DIMENSION A(25),T(25,30),SV(25,30),H(25,30),S(25,30),
     1NUM(25),SSL(14),TSL(14),P(25),AA(5,90),RHOX(90),B(9,8),
     2SONIC(25,30)
   10 FORMAT (8F10.0)
   20 FORMAT (25I3)
C
C**** READ NUMBER OF DATA POINTS FOR EACH ISOBAR
C
      READ (5,20) (NUM(I),I=1,25)
      DO 50 I=1,25
      M=NUM(I)
C
C**** READ TEMPERATURES FOR ISOBAR I
C
      READ (5,10) (T(I,J),J=1,M)
C
C**** READ SPECIFIC VOLUMES FOR ISOBAR I
C
      READ (5,10) (SV(I,J),J=1,M)
C
C**** READ ENTHALPYS FOR ISOBAR I
C
      READ (5,10) (H(I,J),J=1,M)
C
C**** READ ENTROPYS FOR ISOBAR I
C
      READ (5,10) (S(I,J),J=1,M)
C
C**** READ SONIC VELOCITIES FOR ISOBAR I
C
   50 READ (5,10) (SONIC(I,J),J=1,M)
C
C**** CONVERT PRESSURES FROM ATMOSPHERES TO PSIA
C
      A(1)=1.
      A(2)=1.5
      DO 55 I=2,10
   55 A(I+1)=I
      A(12)=12.5
      DO 60 I=1,8
   60 A(I+12)=10+5*I
      DO 65 I=1,5
   65 A(I+20)=50+10*I
      DO 80 I=1,25
   80 P(I)=14.696*A(I)
C
C**** READ CORRESPONDING VALUES OF SATURATED LIQUID TEMPERATURE AND
C**** ENTROPY
C
      READ  (5,10) (TSL(J),J=1,14)
      READ  (5,10) (SSL(J),J=1,14)
   25 FORMAT (5E16.7)
   30 FORMAT (10F8.4)
   35 FORMAT (4E20.8)
```

APPENDIX A

```
C                                                                         FILE 060
C**** READ EMPIRICAL COEFFICIENTS                                          FILE 061
C                                                                         FILE 062
      READ (5,25) ((AA(I,J),J=1,90),I=1,5)                                FILE 063
      READ (5,30) (RHOX(I),I=1,90)                                        FILE 064
      READ (5,35) ((B(I,J),J=1,8),I=1,9)                                  FILE 065
      RETURN                                                              FILE 066
      END                                                                 FILE 067
```

```
C**** SUBROUTINE INTAB ****                                              INTAB000
C**** THIS SUBROUTINE IS USED TO READ IN AND LIST THE TABULATED PUMP     INTAB001
C**** AND TURBINE CHARACTERISTIC CURVES                                  INTAB002
C                                                                        INTAB003
      SUBROUTINE INTAB (IM,ID,IY,K,L,XT,YT,XP,YP,ZP)                     INTAB004
      REAL NIINT,NC(4),IMA,II                                            INTAB005
      DIMENSION K(13),L(4),ZP(4,10),XP(4,30),YP(4,10,30),XT(9,30),       INTAB006
     2YT(9,30)                                                           INTAB007
      DIMENSION CURVE(8,18)                                              INTAB008
    5 FORMAT (I3,5X,18A4/(8F10.0))                                       INTAB009
   10 FORMAT (3A2)                                                       INTAB010
   15 FORMAT ('1'/' DATE ',A2,'-',A2,'-',A2,25X,'TWO-SPOOL TURBOPUMP PERINTAB011
     1FORMANCE PREDICTION',31X,'PAGE ',I3//54X,'CURVES USED'//)          INTAB012
   16 FORMAT (' 1 MAIN TURBINE FLOW PARAMETER........',18A4//            INTAB013
     1' 2 MAIN TURBINE TOTAL EFFICIENCY......',18A4//                    INTAB014
     2' 3 INDUCER TURBINE FLOW PARAMETER.....',18A4//                    INTAB015
     3' 4 INDUCER TURBINE STATIC EFFICIENCY..',18A4/)                    INTAB016
   17 FORMAT (' 5 MAIN PUMP HEAD RISE................',18A4//            INTAB017
     1' 6 MAIN PUMP EFFICIENCY...............',18A4//                    INTAB018
     2' 7 INDUCER PUMP HEAD RISE.............',18A4//                    INTAB019
     3' 8 INDUCER PUMP EFFICIENCY............',18A4///)                  INTAB020
   20 FORMAT (2I3,2X,18A4/(8F10.0))                                      INTAB021
   25 FORMAT (8F10.0)                                                    INTAB022
   30 FORMAT (20X,'MAIN TURBINE',55X,'INDUCER TURBINE'/10X,'(1)',27X,    INTAB023
     1'(2)',37X,'(3)',27X,'(4)'/3X,'TOTAL',6X,'FLOW',14X,'VELOCITY',     INTAB024
     25X,'TOTAL',23X,'STATIC',5X,'FLOW',14X,'VELOCITY',4X,'STATIC'/2X,   INTAB025
     3'PRESSURE',2X,'PARAMETER',13X,'RATIO',6X,'EFF.',23X,'PRESSURE',    INTAB026
     42X,'PARAMETER',13X,'RATIO',5X,'EFF.'/3X,'RATIO',26X,'U/CO',35X,    INTAB027
     5'RATIO',26X,'U/CO'/)                                               INTAB028
   35 FORMAT (F9.3,F10.3)                                                INTAB029
   36 FORMAT ('+',31X,F8.4,F10.3)                                        INTAB030
   37 FORMAT ('+',70X,F8.3,F10.3)                                        INTAB031
   38 FORMAT ('+',101X,F8.4,F10.3)                                       INTAB032
   39 FORMAT (1X)                                                        INTAB033
   40 FORMAT (45X,'MAIN PUMP NORMALIZED HEAD RISE'/59X,'(5)'//2X,        INTAB034
     1'NPSH/N2'  /2X,'FT/RPM2'  ,1X,10E11.3)                             INTAB035
   41 FORMAT (F10.3,10E11.3)                                             INTAB036
   45 FORMAT (50X,'MAIN PUMP EFFICIENCY'/59X,'(6)'//2X,                  INTAB037
     1'NPSH/N2'  /2X,'FT/RPM2'  ,1X,10E11.3)                             INTAB038
   46 FORMAT (11F10.3)                                                   INTAB039
   47 FORMAT (//5X,'Q/N'/4X,'GAL/REV'/)                                  INTAB040
   50 FORMAT (46X,'INDUCER NORMALIZED HEAD RISE'/59X,'(7)'//2X,          INTAB041
     1'NPSH/N2'  /2X,'FT/RPM2'  ,1X,10E11.3)                             INTAB042
   55 FORMAT (51X,'INDUCER EFFICIENCY'/59X,'(8)'//2X,                    INTAB043
     1'NPSH/N2'  /2X,'FT/RPM2'  ,1X,10E11.3)                             INTAB044
      IPAGE=1                                                            INTAB045
C                                                                        INTAB046
C**** READ DATE                                                          INTAB047
C                                                                        INTAB048
      READ (5,10) IM,ID,IY                                               INTAB049
C                                                                        INTAB050
C**** WRITE PAGE 1 TITLE                                                 INTAB051
C                                                                        INTAB052
      WRITE (6,15) IM,ID,IY,IPAGE                                        INTAB053
C                                                                        INTAB054
C**** READ TURBINE TABULATED CURVES                                      INTAB055
C                                                                        INTAB056
      DO 100 I=1,4                                                       INTAB057
C                                                                        INTAB058
```

```
C**** I=1 MAIN TURBINE FLOW PARAMETER CURVE
C**** I=2 MAIN TURBINE EFFICIENCY CURVE
C**** I=3 INDUCER TURBINE FLOW PARAMETER CURVE
C**** I=4 INDUCER TURBINE EFFICIENCY CURVE
C
      READ (5,5) IX,(CURVE(I,M),M=1,18),(XT(I,J),YT(I,J),J=1,IX)
C
C**** SET K(I)=NUMBER OF POINTS ON CURVE
C
  100 K(I)=IX
C
C**** READ INDUCER AND PUMP TABULATED CURVES
C
      DO 120 I=5,8
C
C**** I=5 PUMP NORMALIZED HEAD RISE CURVE
C**** I=6 PUMP EFFICIENCY CURVE
C**** I=7 INDUCER NORMALIZED HEAD RISE
C**** I=8 INDUCER EFFICIENCY
C
C**** READ CURVE IDENTIFICATION AND VALUES OF NPSH/N**2
C
      READ (5,20) IZ,IX,(CURVE(I,M),M=1,18),(ZP(I-4,J),J=1,IZ)
C
C**** READ Q/N VALUES
C
      READ (5,25) (XP(I-4,J),J=1,IX)
C
C**** READ DEL-H/N**2 OR EFFICIENCY VALUES
C
      DO 120 IJ=1,IZ
      READ (5,25) (YP(I-4,IJ,J),J=1,IX)
C
C**** SET K(I)=NUMBER OF POINTS ON CURVE
C
      K(I)=IX
C
C**** SET L=NUMBER OF CURVES
C
  120 L(I-4)=IZ
C
C**** PRINT CURVE TITLES
C
      WRITE (6,16) ((CURVE(I,M),M=1,18),I=1,4)
      WRITE (6,17) ((CURVE(I,M),M=1,18),I=5,8)
C
C**** PRINT TABULATED DATA FOR TURBINE CURVES
C
      WRITE (6,30)
      I=1
      GO TO 160
  150 I=I+1
  160 IF (I-K(1)) 165,165,170
  165 WRITE (6,35) XT(1,I),YT(1,I)
  170 IF (I-K(2)) 175,175,180
  175 WRITE (6,36) XT(2,I),YT(2,I)
  180 IF (I-K(3)) 185,185,190
  185 WRITE (6,37) XT(3,I),YT(3,I)
  190 IF (I-K(4)) 195,195,200
  195 WRITE (6,38) XT(4,I),YT(4,I)
```

```
  200 IF (I-30) 210,230,230
  210 IF (I-K(1)) 150,220,220
  220 WRITE (6,39)
      GO TO 150
C
C**** PRINT TABULATED DATA FOR PUMP NORMALIZED HEAD CURVE
C
  230 IPAGE=2
      WRITE (6,15) IM,ID,IY,IPAGE
      I=L(1)
      WRITE (6,40) (ZP(1,J),J=1,I)
      WRITE (6,47)
      IX=K(5)
      DO 240 J=1,IX
  240 WRITE (6,41) XP(1,J),(YP(1,M,J),M=1,I)
C
C**** PRINT TABULATED DATA FOR PUMP EFFICIENCY CURVE
C
      IPAGE=3
      WRITE (6,15) IM,ID,IY,IPAGE
      I=L(2)
      WRITE (6,45) (ZP(2,J),J=1,I)
      WRITE (6,47)
      IX=K(6)
      DO 250 J=1,IX
  250 WRITE (6,46) XP(2,J),(YP(2,M,J),M=1,I)
C
C**** PRINT TABULATED DATA FOR INDUCER NORMALIZED HEAD CURVE
C
      IPAGE=4
      WRITE (6,15) IM,ID,IY,IPAGE
      I=L(3)
      WRITE(6,50) (ZP(3,J),J=1,I)
      WRITE (6,47)
      IX=K(7)
      DO 260 J=1,IX
  260 WRITE (6,41) XP(3,J),(YP(3,M,J),M=1,I)
C
C**** PRINT TABULATED DATA FOR INDUCER EFFICIENCY CURVE
C
      IPAGE=5
      WRITE (6,15) IM,ID,IY,IPAGE
      I=L(4)
      WRITE (6,55) (ZP(4,J),J=1,I)
      WRITE (6,47)
      IX=K(8)
      DO 270 J=1,IX
  270 WRITE (6,46) XP(4,J),(YP(4,M,J),M=1,I)
      RETURN
      END
```

APPENDIX A

```
C**** SUBROUTINE INPUT ****
C**** THIS SUBROUTINE READS IN THE DATA FOR A PARTICULAR CASE AND LISTS
C**** IT ON PAGE 6 OF THE OUTPUT
C
      SUBROUTINE INPUT (XT,YT,K,QNM,PATM ,IM,IO,IY)
      REAL NIINT,IMA,II
      DIMENSION K(13),XT(9,30),YT(9,30)
      COMMON IFLAG,JFLAG,KFLAG,JPRNT,JPLOT,TMINT,TMAX,XLINE,NIINT,FRI,
     1XLOSS,RM,RI,IMA,II,TPII,AI,AM,AME,D,DTIME,NFLAG
    5 FORMAT (6I5)
   10 FORMAT (7F10.0/(8F10.0))
   15 FORMAT (I5/(8F10.0))
   20 FORMAT ('1'/' DATE ',A2,'-',A2,'-',A2,25X,'TWO-SPOOL TURBOPUMP PER
     1FORMANCE PREDICTION',31X,'PAGE ',I3//)
   30 FORMAT (52X,'INPUT CASE DATA'//'   CONTROL FLAGS-   IFLAG=',I1,
     24X,'JFLAG=',I1,4X,'KFLAG=',I1,4X,'JPRNT=',I1,4X,'JPLOT=',I1
     3,4X,'NFLAG=',I1//
     3' INITIAL TIME',26X,F10.3,'SEC',9X,'FINAL TIME',29X,F10.3,'SEC'//
     4' IND. TURBINE EXHAUST SYS. BACK PRESS. ',F10.1,'PSIA',8X,
     5'ESTIMATED INITIAL INDUCER SPEED',8X,F10.1,'RPM'//
     6' MAIN PUMP FLOW-SPEED RATIO,Q/N',8X,F10.3,'GAL/REV',5X,
     7'TANK TEMPERATURE',23X,F10.1,'DEG R'/)
   31 FORMAT (' SUCTION LINE DIAMETER',17X,F10.3,'FT',10X,
     1'SUCTION LINE LENGTH',20X,F10.2,'FT'//
     2' MAIN TURBINE MEAN BLADE RADIUS',8X,F10.3,'IN',10X,
     3'INDUCER TURBINE MEAN  BLADE RADIUS',5X,F10.3,'IN'//
     4' MAIN ROTATING ASSY. MOMENT OF INERTIA ',F10.3,'LB-IN-SEC2',2X,
     5'INDU. ROTATING ASSY. MOMENT OF INERTIA ',F10.3,'LB-IN-SEC2'/)
   32 FORMAT (' INDUCER INLET AREA',20X,F10.3,'SQ-IN',7X,
     1'PUMP INLET AREA',24X,F10.3,'SQ-IN'//
     2' PUMP DISCHARGE AREA',19X,F10.3,'SQ-IN',7X,
     3'TURBINE EXHAUST LINE LOSS COEFF.',6X,F10.4//
     4' SUCTION LINE FRICTION FACTOR',11X,F10.4/)
   40 FORMAT (5X,'TIME',5X,'TURB. INLET',4X,'TIME',5X,'TURB. INLET',5X,
     1'TIME',4X,'MAIN SHAFT',6X,'TIME',8X,'TANK'/14X,'TEMPERATURE',14X,
     2'PRESSURE',17X,'SPEED',19X,'PRESSURE'/5X,'SEC',8X,'DEG R',8X,
     3'SEC',9X,'PSIA',9X,'SEC',8X,'RPM',10X,'SEC',9X,'PSIA'/)
   41 FORMAT (F11.4,F11.1)
   42 FORMAT ('+',25X,F10.4,F10.1)
   43 FORMAT ('+',49X,F10.4,F10.1)
   44 FORMAT ('+',73X,F10.4,F10.1)
   49 FORMAT (1X)
C
C**** READ CONTROL FLAGS
C
C**** IFLAG=1 TURBINE INLET PRESSURE INPUT
C****      =2 MAIN SHAFT SPEED INPUT
C
C**** JPRNT=1 IF EVERY TIME POINT PRINTED
C****      =2 IF EVERY OTHER POINT PRINTED
C
C**** JFLAG=1 IF SUCTION LINE WATERHAMMER SOLUTION IS TO BE USED
C****      =2 IF NO WATERHAMMER SOLUTION
C
C**** KFLAG=1 IF STEADY STATE CASE
C****      =2 IF TRANSIENT CASE
C
C**** JPLOT=0 IF NO PLOTS
C****      =1 IF ALL TIME POINTS PLOTTED
```

```
C****       =2 IF ONLY PRINTED POINTS PLOTTED
C
C**** NFLAG)0 IF LAST CASE
C****       =0 IF NEXT CASE INVOLVES CHANGE OF CASE DATA ONLY
C****       ,0 IF NEXT CASE INVOLVES NEW TURBOPUMP CHARACTERISTIC CURVES
C
      READ (5,5) IFLAG,JPRNT,JFLAG,KFLAG,JPLOT,NFLAG
C
C**** READ TIME INDEPENDENT DATA
C
      READ (5,10) TMINT,TMAX,PATM ,NIINT,QNM,TPII,DTIME,D,XLINE,RM,RI,
     1IMA,II,AI,AM,AME,XLOSS,FRI
C
C**** READ TIME DEPENDENT DATA
C
C**** I=6 TURBINE INLET TEMPERATURE
C****  =7 TURBINE INLET PRESSURE
C****  =8 MAIN SHAFT SPEED
C****  =9 TANK PRESSURE
C
      DO 50 I=6,9
      READ (5,15) J,(XT(I,M),YT(I,M),M=1,J)
   50 K(I+4)=J
      IPAGE=6
C
C**** LIST CASE DATA
C
      WRITE (6,20) IM,ID,IY,IPAGE
      WRITE (6,30) IFLAG,JFLAG,KFLAG,JPRNT,JPLOT,NFLAG,TMINT,TMAX,
     1PATM ,NIINT,QNM,TPII
      WRITE (6,31) D,XLINE,RM,RI,IMA,II
      WRITE (6,32) AI,AM,AME,XLOSS,FRI
      WRITE (6,40)
      I=0
  150 I=I+1
      IF (I-K(10)) 165,165,170
  165 WRITE (6,41) XT(6,I),YT(6,I)
  170 IF (I-K(11)) 175,175,180
  175 WRITE (6,42) XT(7,I),YT(7,I)
  180 IF (I-K(12)) 185,185,190
  185 WRITE (6,43) XT(8,I),YT(8,I)
  190 IF (I-K(13)) 195,195,200
  195 WRITE (6,44) XT(9,I),YT(9,I)
  200 IF (I-30) 210,230,230
  210 IF (I-K(10)) 150,220,220
  220 WRITE (6,49)
      GO TO 150
  230 RETURN
      END
```

APPENDIX A

```
C**** FINITE DIFFERENCE SOLUTION FOR SUCTION LINE WATERHAMMER
C
      SUBROUTINE INLET (DTIME,W1,W2,P1,P2,SCV,SV,AI,R)
      DIMENSION W1(2),W2(2),P1(2),P2(2),H1(2),H2(2),V1(2),V2(2)
C
C**** COMPUTE LAST TIME POINT SUCTION LINE INLET HEAD
C
      H1(1)=144.*P1(1)*SV
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE INLET HEAD
C
      H1(2)=144.*P1(2)*SV
C
C**** COMPUTE LAST TIME POINT SUCTION LINE DISCHARGE HEAD
C
      H2(1)=144.*P2(1)*SV
C
C**** COMPUTE LAST TIME POINT SUCTION LINE INLET VELOCITY
C
      V1(1)=W1(1)*SV/AI*144.
C
C**** COMPUTE LAST TIME POINT SUCTION LINE DISCHARGE VELOCITY
C
      V2(1)=W2(1)*SV/AI*144.
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE DISCHARGE VELOCITY
C
      V2(2)=W2(2)*SV/AI*144.
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE DISCHARGE HEAD
C
      H2(2)=H1(1)-SCV/32.174*(V2(2)-V1(1))-R*V1(1)*ABS(V1(1))
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE INLET VELOCITY
C
      V1(2)=V2(1)+32.174/SCV*(H1(2)-H2(1)-R*V2(1)*ABS(V2(1)))
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE DISCHARGE PRESSURE
C
      P2(2)=H2(2)/144./SV
C
C**** COMPUTE PRESENT TIME POINT SUCTION LINE INLET FLOW RATE
C
      W1(2)=V1(2)*AI/SV/144.
      RETURN
      END
```

APPENDIX A

```
C**** SUBROUTINE TABIN ****
C**** THIS SUBROUTINE DOES SINGLE INTERPOLATION OF TABULATED DATA
C
      SUBROUTINE TABIN (A,N,K,XT,YT,C,J,XMAX,XMIN)
      REAL NIINT,NC(4),IMA,II
      DIMENSION XT(9,30),YT(9,30),K(13)
C
C**** XT IS THE INDEPENDENT ARRAY
C**** YT IS THE DEPENDENT ARRAY
C**** A IS  THE INDEPENDENT VARIABLE
C**** C IS  THE DEPENDENT VARIABLE
C**** N IS  THE TABLE TO BE INTERPOLATED
C**** J IS  AN ERROR FLAG
C**** K IS  THE TABLE SIZE ARRAY
C
      IF (N-5) 10,15,15
C
C**** SET M=TABLE N SIZE
C
   10 M=K(N)
      GO TO 20
   15 M=K(N&4)
C
C**** SET XMIN=MINIMUM TABLE VALUE
C
   20 XMIN=XT(N,1)
C
C**** SET XMAX=MAXIMUM TABLE VALUE
C
      XMAX=XT(N,M)
      J=1
      I=0
   50 I=I+1
C
C**** SEARCH TABLE FOR VALUE CORRESPONDING TO A
C
      IF (XT(N,I)-A) 60,80,55
C
C**** TABULATED VALUE IS GREATER THAN A,TEST FOR MINIMUM TABLE VALUE
C
   55 IF(I-1) 200,200,90
C
C**** TABULATED VALUE IS LESS THAN A,TEST FOR MAXIMUM VALUE
C
   60 IF (I-M) 50,70,70
C
C**** MAXIMUM TABULATED VALUE IS =OR,A,IF FLOW PARAMETER CURVE USE
C**** MAXIMUM FLOW PARAMETER,IF NOT FLOW PARAMETER CURVE,SET ERROR FLAG
C
   70 GO TO (80,250,80,250,250,250,250,250,250),N
C
C**** TABULATED VALUE = A,SET C= TABULATED VALUE
C
   80 C=YT(N,I)
      GO TO 400
C
C**** INTERPOLATE FOR C
C
   90 C=YT(N,I-1)+(A-XT(N,I-1))/(XT(N,I)-XT(N,I-1))*(YT(N,I)-YT(N,I-1))
      GO TO 400
```

```
C                                                                        TABIN060
C**** MINIMUM TABULATED VALUE IS GREATER THAN A                          TABIN061
C                                                                        TABIN062
  200 J=2                                                                TABIN063
      GO TO 400                                                          TABIN064
C                                                                        TABIN065
C**** MAXIMUM TABULATED VALUE IS LESS THAN A                             TABIN066
C                                                                        TABIN067
  250 J=3                                                                TABIN068
  400 RETURN                                                             TABIN069
      END                                                                TABIN070
```

```
C**** SUBROUTINE TABP ****
C**** THIS SUBROUTINE IS USED FOR DOUBLE INTERPOLATION OF TABULATED
C**** PUMP AND INDUCER DATA
C
      SUBROUTINE TABP (DH,Q,N,K,L,ZP,XP,YP,C,JFLG,XMIN,XMAX)
      REAL NIINT,NC(4),IMA,II
      DIMENSION CP(2)
      DIMENSION K(13),L(4),ZP(4,10),XP(4,30),YP(4,10,30)
C
C**** ZP AND XP ARE THE INDEPENDENT ARRAYS OF NPSH/N**2 AND Q/N DATA
C**** RESPECTIVELY
C**** YP IS THE DEPENDENT ARRAY OF NORMALIZED HEAD RISE AND EFFICIENCY
C**** DH AND Q ARE THE INDEPENDENT VARIABLES NPSH/N**2 AND Q/N
C**** RESPECTIVELY
C**** C IS THE DEPENDENT VARIABLE DEL-H/N**2 OR EFFICIENCY
C**** N IS THE TABLE TO BE INTERPOLATED
C**** JFLG IS AN ERROR FLAG
C**** K IS THE TABLE SIZE ARRAY
C
      JFLG=1
C
C**** SET IY=NUMBER OF NPSH/N**2 CURVES
C
      IY=L(N)
C
C**** SET IX=NUMBER OF Q/N POINTS
C
      IX=K(N+4)
C
C**** SET XMIN=MINIMUM TABULATED Q/N
C
      XMIN=XP(N,1)
C
C**** SET XMAX=MAXIMUM TABULATED Q/N
C
      XMAX=XP(N,IX)
      I=0
   50 I=I+1
C
C**** SEARCH NPSH/N**2 TABLE FOR VALUE CORRESPONDING TO DH
C
      IF (ZP(N,I)-DH) 60,80,55
C
C**** TABULATED VALUE IS GREATER THAN DH,TEST FOR MINIMUM TABLE VALUE
C
   55 IF (I-1) 80,80,150
C
C**** TABULATED VALUE IS LESS THAN DH, TEST FOR MAXIMUM TABLE VALUE
C
   60 IF (I-IY) 50,80,80
C
C**** TABULATED VALUE=DH
C**** OR TABULATED VALUES ARE ALL GREATER THAN DH,USE MINIMUM CURVE
C**** OR TABULATED VALUES ARE ALL LESS THAN DH,USE MAXIMUM CURVE
C
   80 J=0
   85 J=J+1
C
C**** SEARCH Q/N TABLE FOR VALUE CORRESPONDING TO Q
C
```

```
      IF (XP(N,J)-Q) 95,100,90
C
C**** TABULATED VALUE IS GREATER THAN Q,TEST FOR MINIMUM TABLE VALUE
C
   90 IF (J-1) 300,300,110
C
C**** TABULATED VALUE IS LESS THAN Q,TEST FOR MAXIMUM TABLE VALUE
C
   95 IF (J-IX) 85,350,350
C
C**** TABULATED VALUE=Q,SET C=TABULATED VALUE
C
  100 C=YP(N,I,J)
      GO TO 500
C
C**** A SINGLE NPSH/N**2 IS BEING USED,INTERPOLATE FOR C
C
  110 C=YP(N,I,J-1)+(Q-XP(N,J-1))/(XP(N,J)-XP(N,J-1))*(YP(N,I,J)-
     1YP(N,I,J-1))
      GO TO 500
C
C**** DH LIES BETWEEN TWO CURVES OF CONSTANT NPSH/N**2,INTERPOLATE ALONG
C**** EACH CURVE OF NPSH/N**2 FOR PROPER Q/N
C
  150 DO 180 IK=1,2
      JK=IK+I-2
      J=0
  155 J=J+1
C
C**** SEARCH Q/N TABLE FOR VALUE CORRESPONDING TO Q
C
      IF (XP(N,J)-Q) 165,170,160
C
C**** TABULATED VALUE IS GREATER THAN Q,TEST FOR MINIMUM TABLE VALUE
C
  160 IF (J-1) 300,300,175
C
C**** TABULATED VALUE IS LESS THAN Q,TEST FOR MAXIMUM TABLE VALUE
C
  165 IF (J-IX) 155,350,350
C
C**** TABULATED VALUE=Q,SET CP=TABULATED VALUE
C
  170 CP(IK)=YP(N,JK,J)
      GO TO 180
C
C**** INTERPOLATE FOR CP
C
  175 CP(IK)=YP(N,JK,J-1)+(Q-XP(N,J-1))/(XP(N,J)-XP(N,J-1))*(YP(N,JK,J)-
     1YP(N,JK,J-1))
  180 CONTINUE
C
C**** INTERPOLATE FOR C USING CP(1) AND CP(2)
C
      C=CP(1)+(DH-ZP(N,I-1))/(ZP(N,I)-ZP(N,I-1))*(CP(2)-CP(1))
      GO TO 500
C
C**** MINIMUM TABULATED VALUE IS GREATER THAN Q,SET ERROR FLAG
C
```

```
 300 JFLG=2                                                        TABP 119
     GC TC 500                                                     TABP 120
C                                                                  TABP 121
C**** MAXIMUM TAEULATEC VALUE IS LESS THAN Q,SET ERROR FLAG        TABP 122
C                                                                  TABP 123
 350 JFLG=3                                                        TABP 124
 500 RETURN                                                        TABP 125
     ENC                                                           TABP 126
```

APPENDIX A

```
C**** SUBROUTINE SHPIN ****
C**** THIS PROGRAM COMPUTES INDUCER SHAFT POWER AS A FUNCTION OF SPEED
C**** FOR ALL TABULATED Q/N BASED ON A GIVEN FLOW RATE AND NPSH/N**2(DH)
C**** THIS SUBROUTINE REQUIRES THAT INDUCER EFFICIENCY AND NORMALIZED
C**** HEAD BE TABULATED FOR THE SAME Q/N POINTS
C**** CORRESPONDING SPEED AND POWER POINTS ARE STORED IN THE YT AND XT
C**** ARRAYS RESPECTIVELY
C
      SUBROUTINE SHPIN (WP,Q,DH,K,L,ZP,XP,YP,XT,YT)
      REAL NIINT,NC(4),IMA,II
      DIMENSION DHN2(30),EAT(30)
      DIMENSION K(13),L(4),ZP(4,10),XP(4,30),YP(4,10,30),
     1XT(9,30),YT(9,30)
      K(9)=K(8)
      IY=L(3)
      IX=K(7)
      I=0
   50 I=I+1
C
C**** SEARCH NPSH/N**2 TABLE FOR VALUE CORRESPONDING TO DH
C
      IF (ZP(3,I)-DH) 60,80,55
C
C**** TABULATED VALUE GREATER THAN DH
C
   55 IF (I-1) 80,80,150
C
C**** TABULATED VALUE LESS THAN DH
C
   60 IF (I-IY) 50,80,80
C
C**** TABULATED VALUE=DH
C**** OR TABULATED VALUES ARE ALL GREATER THAN DH,USE MINIMUM CURVE
C**** OR TABULATED VALUES ARE ALL LESS THAN DH,USE MAXIMUM CURVE
C
   80 DO 85 J=1,IX
C
C**** SET UP ONE DIMENSIONAL ARRAY,DHN2, OF DELH/N**2 POINTS
C
      DHN2(J)=YP(3,I,J)
C
C**** SET UP ONE DIMENSIONAL ARRAY,EAT,OF EFFICIENCY POINTS
C
   85 EAT(J)=YP(4,I,J)
      GO TO 200
  150 IJ=I+2
      IJ=I+1
      DO 190 J=1,IX
C
C**** INTERPOLATE FOR ONE DIMENSIONAL ARRAY,DHN2,OF DELH/N**2 POINTS
C
      DHN2(J)=YP(3,I-1,J)+(DH-ZP(3,I-1))/(ZP(3,I)-ZP(3,I-1))*(YP(3,I,J)
     1-YP(3,I-1,J))
C
C**** INTERPOLATE FOR ONE DIMENSIONAL ARRAY,EAT,OF EFFICIENCY POINTS
C
  190 EAT(J)=YP(4,I-1,J)+(DH-ZP(3,I-1))/(ZP(3,I)-ZP(3,I-1))*(YP(4,I,J)
     1-YP(4,I-1,J))
  200 DO 250 J=1,IX
C
```

```
C**** START CALCULATIONS WITH MAXIMUM TABULATED Q/N WHICH GIVES MINIMUM SHPIN060
C**** POWER                                                             SHPIN061
C                                                                       SHPIN062
      M=IX-J+1                                                          SHPIN063
C                                                                       SHPIN064
C**** TEST Q/N,IF 0 SET N=INFINITY AND POWER=0                          SHPIN065
C                                                                       SHPIN066
      IF (XP(3,M)) 210,210,220                                          SHPIN067
  210 YT(5,J)=1.0E+70                                                   SHPIN068
      XT(5,J)=0.0                                                       SHPIN069
      GO TO 250                                                         SHPIN070
C                                                                       SHPIN071
C**** Q/N IS NON ZERO,COMPUTE N=Q/(Q/N)                                 SHPIN072
C                                                                       SHPIN073
  220 YT(5,J)=Q/XP(3,M)                                                 SHPIN074
C                                                                       SHPIN075
C**** TEST EFFICIENCY,IF 0 SET POWER=0                                  SHPIN076
C                                                                       SHPIN077
      IF (EAT(M)) 230,230,240                                           SHPIN078
  230 XT (5,J)=0.0                                                      SHPIN079
      GO TO 250                                                         SHPIN080
C                                                                       SHPIN081
C**** EFFICIENCY IS NON ZERO,COMPUTE POWER                              SHPIN082
C                                                                       SHPIN083
  240 XT(5,J)=WP*DHN2(M)/EAT(M)/550.*YT(5,J)**2                         SHPIN084
  250 CONTINUE                                                          SHPIN085
      RETURN                                                            SHPIN086
      END                                                               SHPIN087
```

APPENDIX A

```
C**** SUBROUTINE PRATO ****
C**** THIS SUBROUTINE IS USED TO DETERMINE AN APPROXIMATE INITIAL MAIN
C**** TURBINE PRESSURE RATIO BASED ON PUMP POWER,TURBINE INLET TEMP.,
C**** BACK PRESSURE,AND SPEED
C
      SUBROUTINE PRATO (SHPPM,T,P,U,G,CP,CT,XT,YT,K,PRF,PARMN,PARMX,UCO,
     1J)
      DIMENSION XT(9,30),YT(9,30),PR(50),K(13)
      C=((G-1.)/G)
      I=0
  100 I=I+1
C
C**** TAKE PRESSURE RATIO FROM TABLE
C
      PR(I)=XT(1,I)
C
C**** USE CORRESPONDING FLOW PARAMETER
C**** AFTER MAXIMUM TABULATED PRESSURE RATIO IS REACHED,INCREASE
C**** PRESSURE RATIO BY A FACTOR OF 1.2
C
      FP=YT(1,I)
      GO TO 105
  102 I=I+1
      PR(I)=1.2*PR(I-1)
  105 IF(PR(I)-1.) 106,106,107
C
C**** FOR PRESSURE RATIO=1.,SET POWER EQUAL TO 0.
C
  106 SHPF=0.
      GO TO 151
C
C**** COMPUTE IDEAL ENTHALPY DROP
C
  107 DHI=CP*T*(1.-(1./PR(I))**C)
      CO=SQRT(CT*DHI)
      UCO=U/CO
C
C**** INTERPOLATE FOR MAIN TURBINE EFFICIENCY
C
      CALL TABIN (UCO,2,K,XT,YT,EAT,J,PARMX,PARMN)
      GO TO (110,300,151),J
C
C**** COMPUTE ACTUAL ENTHALPY DROP
C
  110 DH=DHI*EAT
C
C**** TURBINE INLET TOTAL PRESSURE
C
      PTTI=P*PR(I)
C
C**** TURBINE FLOW RATE
C
      WT=FP*PTTI/SQRT(T)
C
C**** TURBINE POWER
C
      SHP=WT*DH*778.16/550.
C
C**** COMPARE TURBINE POWER WITH PUMP POWER
C
```

```
      IF (SHP-SHPPM) 150,250,200                                        PRAT0060
  150 SHPF=SHP                                                          PRAT0061
C                                                                       PRAT0062
C**** TEST FOR END OF TABLE                                             PRAT0063
C                                                                       PRAT0064
  151 IF(I-K(1)) 100,155,155                                            PRAT0065
C                                                                       PRAT0066
C**** TEST FOR 50 POINTS                                                PRAT0067
C                                                                       PRAT0068
  155 IF(I-50) 102,300,300                                              PRAT0069
  200 IF (I-1) 210,210,220                                              PRAT0070
C                                                                       PRAT0071
C**** TURBINE POWER IS GREATER THAN PUMP POWER FOR MINIMUM TABULATED    PRAT0072
C**** PRESSURE RATIO,INTERPOLATE FOR PRESSURE RATIO                     PRAT0073
C                                                                       PRAT0074
  210 PRF=(PR(I)-1.0)/SHP*(SHP-SHPPM)                                   PRAT0075
      GO TO 300                                                         PRAT0076
C                                                                       PRAT0077
C**** TURBINE POWER IS GREATER THAN PUMP POWER,INTERPOLATE FOR PRESSURE PRAT0078
C**** RATIO                                                             PRAT0079
C                                                                       PRAT0080
  220 PRF=PR(I)+(PR(I)-PR(I-1))/(SHP-SHPF)*(SHP-SHPPM)                  PRAT0081
      GO TO 300                                                         PRAT0082
  250 PRF=PR(I)                                                         PRAT0083
  300 RETURN                                                            PRAT0084
      END                                                               PRAT0085
```

```
C**** SUBROUTINE HPROP ****
C**** THIS SUBROUTINE PROVIDES THE FOLLOWING HYDROGEN PROPERTIES DATA TO
C**** THE MAIN PROGRAMO
C**** SUCTION LINE SONIC VELOCITY AS A FUNCTION OF TEMPERATURE AND
C**** PRESSURE
C**** INDUCER INLET SPECIFIC VOLUME AS A FUNCTION OF TEMPERATURE AND
C**** PRESSURE
C**** PUMP INLET SPECIFIC VOLUME AS A FUNCTION OF TEMPERATURE AND
C**** PRESSURE
C
      SUBROUTINE HPROP (A,B,Y,X,KJ,K,N,P,D,C,JFLG,XMIN,XMAX)
      DIMENSION X(25,30),Y(25,30),N(25),P(25),CP(2),D(9,8)
C
C**** P IS THE PRESSURE ARRAY
C**** X IS THE INDEPENDENT PROPERTY ARRAY
C**** Y IS THE DEPENDENT PROPERTY ARRAY
C**** N IS THE OF DATA POINTS FOR EACH ISOBAR ARRAY
C**** A IS PRESSURE
C**** B IS THE SECOND INDEPENDENT VARIABLE
C**** KJ DETERMINES THE INDEPENDENT PARAMETER USED
C**** KJ=1,B IS TEMPERATURE
C**** KJ NOT=1,B IS SPECIFIC VOLUME,ENTHALPY,ENTROPY OR SONIC VELOCITY
C**** K DETERMINES THE DEPENDENT PARAMETER REQUESTED
C**** K=1,C IS TEMPERATURE
C**** K=2,C IS SPECIFIC VOLUME
C**** K=3,C IS ENTHALPY
C**** K=4,C IS ENTROPY
C**** K=5,C IS SONIC VELOCITY
C**** C IS THE REQUESTED DEPENDENT PROPERTY
C**** D IS THE ARRAY OF EMPIRICAL CONSTANTS USED IN THE SATURATED
C**** PRESSURE SUBPROGRAM SVSL
C
      JFLG=1
      I=0
      LIMIT=0
C
C**** SET XMIN=MINIMUM TABULATED PRESSURE
C
      XMIN=P(1)
C
C**** SET XMAX=MAXIMUM TABULATED PRESSURE
C
      XMAX=P(25)
   50 I=I+1
C
C**** SEARCH PRESSURE TABLE FOR VALUE CORRESPONDING TO A
C
      IF(P(I)-A) 60,80,55
C
C**** TABULATED PRESSURE IS GREATER THAN A,TEST FOR MINIMUM TABLE VALUE
C
   55 IF (I-1) 200,200,150
C
C**** TABULATED PRESSURE IS LESS THAN A,TEST FOR MAXIMUM TABLE VALUE
C
   60 IF (I-25) 50,250,250
C
C**** TABULATED PRESSURE=A
C
```

```
   80 M=N(I)
C
C**** SET XMIN=MINIMUM TABULATED INDEPENDENT PROP.
C
      XMIN=X(I,1)
C
C**** SET XMAX=MAXIMUM TABULATED INDEPENDENT PROP.
C
      XMAX=X(I,M)
      J=0
   85 J=J+1
C
C**** SEARCH INDEPENDENT PROPERTY TABLE FOR VALUE CORRESPONDING TO B
C
      IF (X(I,J)-B) 95,100,90
C
C**** TABULATED PROP. IS GREATER THAN B,TEST FOR MINIMUM TABLE VALUE
C
   90 IF (J-1) 300,300,110
C
C**** TABULATED PROP. IS LESS THAN B,TEST FOR MAXIMUM TABLE VALUE
C
   95 IF (J-M) 85,350,350
C
C**** TABULATED PROP=B,SET C=TABULATED VALUE
C
  100 C=Y(I,J)
      GO TO 500
C
C**** INTERPOLATE ALONG ISOBAR I FOR C
C
  110 C=Y(I,J-1)+(B-X(I,J-1))/(X(I,J)-X(I,J-1))*(Y(I,J)-Y(I,J-1))
      GO TO 500
C
C**** A LIES BETWEEN TWO TABULATED ISOBARS,INTERPOLATE ALONG EACH ISOBAR
C**** FOR PROPER B
C
  150 NM=I-1
      DO 180 IK=NM,I
      M=N(IK)
      JK=IK-I+2
      J=0
C
C**** SET XMIN=MINIMUM TABULATED INDEPENDENT PROP.
C
      XMIN=X(IK,1)
C
C**** SET XMAX=MAXIMUM TABULATED INDEPENDENT PROP.
C
      XMAX=X(IK,M)
  155 J=J+1
C
C**** SEARCH INDEPENDENT PROPERTY TABLE FOR VALUE CORRESPONDING TO B
C
      IF (X(IK,J)-B) 165,170,160
C
C**** TABULATED PROP. IS GREATER THAN B,TEST FOR MINIMUM TABLE VALUE
C
  160 IF (J-1) 300,300,550
C
```

```
C**** TABULATED PROP. IS LESS THAN B,TEST FOR MAXIMUM TABLE VALUE
C
  165 IF (J-N(IK)) 155,510,510
C
C**** TABULATED VALUE=B,SET CP=TABULATED VALUE
C
  170 CP(JK)=Y(IK,J)
      GO TO 180
C
C**** MAXIMUM TABULATED VALUE IS LESS THAN B,IF ISOBAR LESS THAN A SET
C**** LIMIT=1 AND CONTINUE,IF ISOBAR GREATER THAN A SET ERROR FLAG AND
C**** RETURN
C
  510 IF (JK-1) 520,520,350
  520 LIMIT = 1
      GO TO 180
C
C**** CHECK LIMIT SET=1
C
  550 IF (LIMIT) 175,175,600
C
C**** LIMIT=0,NORMAL INTERPOLATION SEQUENCE ON ISOBAR
C
  175 CP(JK)=Y(IK,J-1)+(B-X(IK,J-1))/(X(IK,J)-X(IK,J-1))*
     1(Y(IK,J)-Y(IK,J-1))
  180 CONTINUE
C
C**** NORMAL INTERPOLATION FOR C
C
      C=CP(1)+(A-P(I-1))/(P(I)-P(I-1))*(CP(2)-CP(1))
      GO TO 500
C
C**** LIMIT=1,CHECK FOR TEMPERATURE AS INDEPENDENT PROPERTY
C
  600 IF (KJ-1) 350,610,350
C
C**** TEMPERATURE IS INDEPENDENT PROPERTY,FIND CORRESPONDING VAPOR
C**** PRESSURE
C
  610 PSL=VPFUN(B)
      GO TO (620,620,630,640,645),K
C
C**** FIND STAURATED LIQUID SPEC. VOL. CORRESPONDING TO TEMPERATURE=B
C
  620 CP(2)=SVSL(B,D)
      GO TO 650
C
C**** FIND SATURATED LIQUID ENTHALPY CORRESPONDING TO TEMPERATURE=B
C
  630 CP(2)=-17.48568-6.608043*B+.1124545*B**2
      GO TO 650
C
C**** FIND SATURATED LIQUID ENTROPY CORRESPONDING TO TEMPERATURE=B
C
  640 CP(2)=1.644557-.03544848*B+.001182212*B**2
      GO TO 650
C
C**** SET SATURATED LIQUID SONIC VELOCITY
C
```

```
  645 CP(2)=3940.                                                        HPROP178
C                                                                        HPROP179
C**** INTEFCLATE FCR CF CN ISOBAR GREATER THAN A                          HPROP180
C                                                                        HPROP181
  650 CP(1)=Y(I,J-1)+(B-X(I,J-1))*(Y(I,J)-Y(I,J-1))/(X(I,J)-X(I,J-1))    HPROP182
C                                                                        HPROP183
C**** INTEFCLATE FCR C USING SATURATED CONDITIONS                         HPROP184
C                                                                        HPROP185
      C=CP(1)+(A-P(I))*(CP(2)-CP(1))/(PSL-P(I))                          HPROP186
      GO TC 500                                                          HPROP187
C                                                                        HPROP188
C**** MINIMUM TABULATEC PRESSURE IS GREATER THAN A,SET ERROR FLAG         HPROP189
C                                                                        HPROP190
  200 JFLG=2                                                             HPROP191
      GO TC 500                                                          HPROP192
C                                                                        HPROP193
C**** MAXIMUM TABULATED PRESSURE IS LESS THAN A,SET ERROR FLAG            HPROP194
C                                                                        HPROP195
  250 JFLG=3                                                             HPROP196
      GO TC 500                                                          HPROP197
C                                                                        HPROP198
C**** MINIMUM TABULATEC INDEPENDENT PROP. IS GREATER THAN B,SET ERROR     HPROP199
C**** FLAG                                                               HPROP200
C                                                                        HPROP201
  300 JFLG=4                                                             HPROP202
      GO TC 500                                                          HPROP203
C                                                                        HPROP204
C**** MAXIMUM TAEULATEC INDEPENDENT PROP. IS LESS THAN B,SET ERROR FLAG HPROP205
C                                                                        HPROP206
  350 JFLG=5                                                             HPROP207
  500 RETURN                                                             HPROP208
      END                                                                HPROP209
```

APPENDIX A

```
C**** SUBROUTINE GAMMA ****
C**** THIS SUBPROGRAM PROVIDES SPECIFIC HEAT RATIO DATA TO THE MAIN
C**** PROGRAM FOR HYDROGEN GAS
C
      FUNCTION GAMMA(T,P)
C
C**** TEST FOR ABSOLUTE TEMPERATURE LESS THAN 1100 DEG-R
C
      IF (T-1100.) 50,50,100
C
C**** TEMPERATURE IS LESS THAN 1100 DEG-R,COMPUTE COEFFICIENTS AS A
C**** FUNCTION OF PRESSURE
C
   50 C1=1.2737+6.286E-05*P
      C2=1.0E-03*(0.2876-1.32E-04*P)
      C3=1.0E-06*(-0.164+6.92E-05*P)
      GO TO 150
C
C**** TEMPERATURE IS GREATER THAN 1100 DEG-R,COMPUTE COEFFICIENTS AS A
C**** FUNCTION OF PRESSURE
C
  100 C1=1.4032+1.05E-05*P
      C2=1.0E-05*(0.629-1.49E-03*P)
      C3=1.0E-07*(-0.1074+4.4E-05*P)
C
C**** COMPUTE GAMMA
C
  150 GAMMA=C1+C2*T+C3*T**2
      RETURN
      END
```

APPENDIX A

```
C**** FUNCTICN SUBPROGRAM CP ****
C**** THIS SUBPRCGRAM PROVIDES CONSTANT PRESSURE SPECIFIC HEAT DATA TO
C**** THE MAIN PRCGRAM FOR HYDROGEN GAS
C
      FUNCTICN CP (T,P)
C
C**** TEST FOR ABSCLUTE TEMPERATURE LESS THAN 800 DEG-R
C
      IF (T-800.) 50,50,100
C
C**** TEMPERATURE IS LESS THAN 800 DEG-R,COMPUTE COEFFICIENTS AS A
C**** FUNCTICN CF PRESSURE
C
   50 C1=4.6962+2.18E-04*P
      C2=-1.0E-02*(0.3179+4.853E-05*P)
      C3=1.0E-05*(0.2051+2.8E-05*P)
      GC TC 150
C
C**** TEMPERATURE IS GREATER THAN 800 DEG-R,COMPUTE COEFFICIENTS AS A
C**** FUNCTICN CF PRESSURE
C
  100 C1=3.5628+4.453E-05*P
      C2=-1.0E-C3*(0.2151+4.773E-05*P)
      C3=1.0E-C6*(0.12585+1.293E-05*P)
C
C**** CCMPUTE CP
C
  150 CP=C1+C2*T+C3*T**2
      RETURN
      ENC
```

APPENDIX A

```
C**** FUNCTION SUBPROGRAM SVSL ****
C**** THIS SUBPROGRAM IS USED TO COMPUTE SATURATED LIQUID SPECIFIC
C**** VOLUME FOR HYDROGEN
C
      FUNCTION SVSL(T,A)
      DIMENSION A(9,8)
C
C**** T=TEMPERATURE IN DEG-R
C**** TL=DIFFERENCE BETWEEN CRITICAL AND FLUID TEMPERATURES,DEG-K
C**** CRITICAL TEMPERATURE=32.976 DEG-K
C
      TL=32.976-T/1.8
C**** RHOC=CRITICAL DENSITY
C
C
      RHOC=0.01559
C**** RHOSL=SATURATION DENSITY
C
C
      RHOSL=RHOC+A(1,1)*TL**.380+A(1,2)*TL+A(1,3)*TL**(4./3.)+A(1,4)*
     2TL**(5./3.)+A(1,5)*TL**2
      RHOSL=RHOSL/0.0079467
C**** SVSL=SATURATED LIQUID SPECIFIC VOLUME
C
C
      SVSL=1./RHOSL
      RETURN
      END
```

APPENDIX A

```
C**** SUBROUTINE VPFUN ****
C**** THIS SUBPROGRAM IS USED TO COMPUTE SATURATION PRESSURE AS A
C**** FUNCTION OF TEMPERATURE
C
      FUNCTION VPFUN (TSL)
      DIMENSION A(4)
      C=.05357*TSL-1.678
      A(1)=2.00062
      A(2)=-50.09708
      A(3)=1.0044
      A(4)=.01748495
C
C**** TSL=TEMPERATURE,DEG-R
C**** T=TEMPERATURE,DEG-K
C
      T  =TSL/1.8
      ICNT=0
C
C**** USE APPROXIMATE POLYNOMIAL CURVE FIT TO INITIALIZE SATURATION
C**** PRESSURE
C
      PSL=(301.2628-17.1219*TSL+.2549671*TSL**2)/14.696
C
C**** USE MODIFIED METHOD OF SUCCESSIVE APPROXIMATIONS TO OBTAIN
C**** SATURATION PRESSURE,PSL
C
    3 ICNT=ICNT+1
      P=PSL
      FPSL=(-(A(3)*A(4)+A(1)-0.4342945*ALOG(P))+SQRT((A(3)
     2*A(4)+A(1)-0.4342945*ALOG(P))**2-4.*A(4)*(A(3)*A(1)
     3+A(2)-0.4342945*ALOG(P))))/(2.*A(4))
      PSL=PSL+(T -FPSL)*C
      IF(ABS((PSL-P)/PSL)-.0001)1,1,2
    2 IF(ICNT-30)3,1,1
    1 VPFUN=PSL*14.696
      RETURN
      END
```

```
C**** SUBROUTINE OUT1 ****
C**** THIS SUBROUTINE PRINTS THE OUTPUT FOR TRANSIENT CASES AT THE
C**** SPECIFIED PRINT INTERVAL
C
      SUBROUTINE OUT1(CALC1,NCT,IM,ID,IY,IPAGE)
      DIMENSION CALC1(75,50)
   10 FORMAT ('1'/' DATE 'A2,'-',A2,'-',A2,25X,'TWO-SPOOL TURBOPUMP PERF
     1ORMANCE PREDICTION',31X,'PAGE ',I3)
   15 FORMAT (/48X,'INDUCER AND SUCTION LINE')
   20 FORMAT (/4X,'TIME',6X,'PSLI',6X,'PII',7X,'TII',7X,'SVI',7X,'WSLI',
     16X,'QII',8X,'WI',7X,'PTII',7X,'NI',7X,'Q/NI',6X,'DPI'/5X,'SEC'
     26X,'PSIA',6X,'PSIA',5X,'DEG-R',4X,'FT**3/LB',3X,'LB/SEC',5X,'GPM',
     36X,'LB/SEC',5X,'PSIA',6X,'RPM',6X,'GAL/REV',4X,'PSI'/)
   25 FORMAT (F10.4,F9.2,2F10.2,F10.3,F10.1,2F10.2,F10.1,F9.1,2F10.2)
   30 FORMAT (/4X,'TIME',6X,'PTIE',7X,'PIE',8X,'DHI',6X,'DHI/N**2',7X,
     1'NPSPI',5X,'NPSHI',5X,'NPSH/N**2',5X,'EATPI',6X,'SHPI',5X,'TORQI'/
     25X,'SEC',6X,'PSIA',7X,'PSIA',7X,'FT',7X,'FT/RPM**2',6X,'PSI',7X,
     3'FT',8X,'FT/RPM**2',17X,'HP',6X,'FT-LB'/)
   35 FORMAT (F10.4,F9.2,F10.2,F10.1,E16.5,F10.2,F10.1,E14.5,F10.3,
     12F11.1)
   40 FORMAT (/55X,'MAIN PUMP')
   45 FORMAT (/4X,'TIME',6X,'PMI',7X,'PTMI',6X,'TMI',7X,'SVM',7X,'QMI',
     18X,'WP',8X,'NM',7X,'Q/NM',6X,'DPM',7X,'PTME',6X,'PME'/5X,'SEC',
     26X,'PSIA',6X,'PSIA',5X,'DEG-R',4X,'FT**3/LB',4X,'GPM',6X,'LB/SEC',
     36X,'RPM',
     45X,'GAL/REV',4X,'PSI',7X,'PSIA',6X,'PSIA'/)
   50 FORMAT (F10.4,F9.2,2F10.2,F10.3,F10.1,F10.2,F11.1,F9.3,3F10.2)
   55 FORMAT (/4X,'TIME',6X,'DHM',8X,'DHM/N**2',6X,'NPSPM',5X,'NPSHM',
     15X,'NPSH/N**2',5X,'EATPM',6X,'SHPM',5X,'TORQM'/5X,'SEC',
     26X,'FT',9X,'FT/RPM**2',6X,'PSI',7X,'FT',7X,'FT/RPM**2',17X,'HP',
     36X,'FT-LB'/)
   60 FORMAT (F10.4,F10.1,E14.5,F10.2,F10.1,E14.5,F10.3,2F11.1)
   65 FORMAT (/52X,'INDUCER TURBINE')
   70 FORMAT (/4X,'TIME',6X,'PTTII',5X,'TTII',6X,'PTEI',7X,'PRI',7X,'WT'
     1,8X,'FPI',6X,'DHTI',6X,'COI',7X,'UCOI',6X,'EATTI',5X,'SHPTI'/5X,
     2'SEC',6X,'PSIA',5X,'DEG-R',6X,'PSIA',15X,'LB/SEC',14X,'BTU/LB',4X,
     3'FT/SEC',26X,'HP'/)
   75 FORMAT (F10.4,F9.2,F10.1,F10.2,F10.3,F10.2,F10.3,F10.1,F11.1,
     1F9.3,F10.3,F11.1)
   80 FORMAT (4X,'TIME',5X,'TORQIT'/5X,'SEC',5X,'FT-LB'/)
   85 FORMAT (F10.4,F9.1)
   90 FORMAT (/53X,'MAIN TURBINE')
   95 FORMAT (/4X,'TIME',6X,'PTTIM',5X,'TTIM',6X,'PTTEM',6X,'PRM',7X,
     1'WT',8X,'FPM',6X,'DHTM',6X,'COM',7X,'UCOM',6X,'EATTM',5X,'SHPTM'/
     25X,'SEC',6X,'PSIA',5X,'DEG-R',6X,'PSIA',15X,'LB/SEC',14X,'BTU/LB',
     34X,'FT/SEC',26X,'HP'/)
  100 FORMAT (4X,'TIME',5X,'TORQMT'/5X,'SEC',5X,'FT-LB'/)
      IPAGE=IPAGE+1
      WRITE (6,10) IM,ID,IY,IPAGE
      WRITE (6,15)
      WRITE (6,20)
      WRITE (6,25) (CALC1(1,J),(CALC1(I,J),I=2,12),J=1,NCT)
      IPAGE=IPAGE+1
      WRITE (6,10) IM,ID,IY,IPAGE
      WRITE (6,15)
      WRITE (6,30)
      WRITE (6,35) (CALC1(1,J),(CALC1(I,J),I=13,22),J=1,NCT)
      IPAGE=IPAGE+1
      WRITE (6,10) IM,ID,IY,IPAGE
```

```
WRITE (6,40)
WRITE (6,45)
WRITE (6,50) (CALC1(1,J),(CALC1(I,J),I=23,33),J=1,NCT)
IPAGE=IPAGE+1
WRITE (6,10) IM,ID,IY,IPAGE
WRITE (6,40)
WRITE (6,55)
WRITE (6,60)(CALC1(1,J),(CALC1(I,J),I=34,41),J=1,NCT)
IPAGE=IPAGE+1
WRITE (6,10) IM,ID,IY,IPAGE
WRITE (6,65)
WRITE (6,70)
WRITE (6,75) (CALC1(1,J),(CALC1(I,J),I=42,52),J=1,NCT)
IPAGE=IPAGE+1
WRITE (6,10) IM,ID,IY,IPAGE
WRITE (6,65)
WRITE (6,80)
WRITE (6,85) (CALC1(1,J),CALC1(53,J),J=1,NCT)
IPAGE=IPAGE+1
WRITE (6,10) IM,ID,IY,IPAGE
WRITE (6,90)
WRITE (6,95)
WRITE (6,75) (CALC1(1,J),(CALC1(I,J),I=54,64),J=1,NCT)
IPAGE=IPAGE+1
WRITE (6,10) IM,ID,IY,IPAGE
WRITE (6,90)
WRITE (6,100)
WRITE (6,85) (CALC1(1,J), CALC1(65,J),J=1,NCT)
RETURN
END
```

```
C**** SUBROUTINE OUT2 ****
C**** THIS SUBROUTINE PRINTS THE OUTPUT FOR INTERMEDIATE TIME POINTS OF
C**** TRANSIENT CASES
C
      SUBROUTINE OUT2 (CALC2,MCT,IM,ID,IY,IPAGE)
      DIMENSION CALC2(12,50)
   10 FORMAT ('1'/' DATE 'A2,'-',A2,'-',A2,25X,'TWO-SPOOL TURBOPUMP PERF
     1ORMANCE PREDICTION',31X,'PAGE ',I3)
   15 FORMAT (/48X,'INDUCER AND SUCTION LINE'/48X,'INTERMEDIATE TIME POI
     1NTS')
   20 FORMAT (/4X,'TIME',6X,'PSLI',6X,'PII',7X,'TII',7X,'SVI',7X,'WSLI',
     16X,'CII',8X,'WI',7X,'PTII',7X,'NI',7X,'Q/NI',6X,'DPI'/5X,'SEC'
     26X,'PSIA',6X,'PSIA',5X,'DEG-R',4X,'FT**3/LB',3X,'LB/SEC',5X,'GPM',
     36X,'LB/SEC',5X,'PSIA',6X,'RPM',6X,'GAL/REV',4X,'PSI'/)
   25 FORMAT (F10.4,F9.2,2F10.2,F10.3,F10.1,2F10.2,F11.1,F9.3,2F10.2)
      IPAGE=IPAGE+1
      WRITE (6,10) IM,ID,IY,IPAGE
      WRITE (6,15)
      WRITE (6,20)
      WRITE (6,25) (CALC2(1,J),(CALC2(I,J),I=2,12),J=1,MCT)
      RETURN
      END
```

```
C**** SUBRCUTINE CUT3 ****
C**** THIS SUBRCUTINE PRINTS THE OUTPUT FOR STEADY STATE CASES
C
      SUBRCUTINE CUT3 (CATA1,IM,ID,IY,IPAGE)
      DIMENSICN CATA1(75)
   10 FCRMAT ('1'/' CATE 'A2,'-',A2,'-',A2,25X,'TWO-SPCOL TURBOPUMP PERF
     1ORMANCE PRECICTION',31X,'PAGE ',I3)
   15 FCRMAT (/51X,'**** INDUCER ****')
   20 FCRMAT (/           6X,'PSLI',6X,'PII',7X,'TII',7X,'SVI',7X,'WSLI',
     16X,'CII',8X,'WI',7X,'PTII',7X,'NI',7X,'Q/NI',6X,'DPI'/
     26X,'FSIA',6X,'PSIA',5X,'DEG-R',4X,'FT**3/LB',3X,'LB/SEC',5X,'GPM',
     36X,'LB/SEC',5X,'PSIA',6X,'RPM',6X,'GAL/REV',4X,'PSI'/)
   25 FCRMAT (       F9.2,2F10.2,F10.3,F10.1,2F10.2,F10.1,F9.1,2F10.2//)
   30 FCRMAT (/           6X,'PTIE',7X,'PIE',8X,'DHI',6X,'DHI/N**2',7X,
     1'NPSPI',5X,'NPSHI',5X,'NPSH/N**2',5X,'EATPI',6X,'SHPI',5X,'TORQI'/
     2          6X,'PSIA',7X,'PSIA',7X,'FT',7X,'FT/RPM**2',6X,'PSI',7X,
     3'FT',8X,'FT/RPM**2',17X,'HP',6X,'FT-LB'/)
   35 FORMAT (       F9.2,F10.2,F10.1,E16.5,F10.2,F10.1,E14.5,F10.3,
     12F11.1//)
   40 FCRMAT (53X,'**** PUMP ****')
   45 FCRMAT (/           6X,'PMI',7X,'PTMI',6X,'TMI',7X,'SVM',7X,'QMI',
     18X,'WP',8X,'NM',7X,'Q/NM',6X,'DPM',7X,'PTME',6X,'PME'/
     26X,'FSIA',6X,'PSIA',5X,'DEG-R',4X,'FT**3/LB',4X,'GPM',6X,'LB/SEC',
     36X,'RPM',
     45X,'GAL/REV',4X,'PSI',7X,'PSIA',6X,'PSIA'/)
   50 FCRMAT (       F9.2,2F10.2,F10.3,F10.1,F10.2,F11.1,F9.3,3F10.2//)
   55 FCRMAT (/           6X,'DHM',8X,'DHM/N**2',6X,'NPSPM',5X,'NPSHM',
     15X,'NPSH/N**2',5X,'EATPM',6X,'SHPM',5X,'TORQM'/
     26X,'FT',9X,'FT/RPM**2',6X,'PSI',7X,'FT',7X,'FT/RPM**2',17X,'HP',
     36X,'FT-LB'/)
   60 FCRMAT (       F10.1,E14.5,F10.2,F10.1,E14.5,F10.3,2F11.1//)
   65 FCRMAT (48X,'**** INDUCER TURBINE ****')
   70 FCRMAT (/           6X,'PTTII',5X,'TTII',6X,'PTEI',7X,'PRI',7X,'WT'
     1,8X,'FPI',6X,'DHTI',6X,'COI',7X,'UCOI',6X,'EATTI',5X,'SHPTI'/
     2       6X,'PSIA',5X,'DEG-R',6X,'PSIA',15X,'LB/SEC',14X,'BTU/LB',4X,
     3'FT/SEC',26X,'HP'/)
   75 FCRMAT (       F9.2,F10.1,F10.2,F10.3,F10.2,F10.3,F10.1,F11.1,
     1F9.3,F10.3,F11.1//)
   80 FCRMAT (/         5X,'TORQIT'/          5X,'FT-LB'/)
   85 FCRMAT (F9.1//)
   90 FCRMAT (49X,'**** MAIN TURBINE ****')
   95 FCRMAT (/           6X,'PTTIM',5X,'TTIM',6X,'PTTEM',6X,'PRM',7X,
     1'WT',8X,'FPM',6X,'DHTM',6X,'COM',7X,'UCOM',6X,'EATTM',5X,'SHPTM'/
     2          6X,'PSIA',5X,'DEG-R',6X,'PSIA',15X,'LB/SEC',14X,'BTU/LB',
     34X,'FT/SEC',26X,'HP'/)
  100 FCRMAT (/         5X,'TORQMT'/          5X,'FT-LB'/)
      IPAGE=IPAGE+1
      WRITE (6,10) IM,ID,IY,IPAGE
      WRITE (6,15)
      WRITE (6,20)
      WRITE (6,25) (CATA1(I),I=2,12)
      WRITE (6,30)
      WRITE (6,35) (CATA1(I),I=13,22)
      WRITE (6,40)
      WRITE (6,45)
      WRITE (6,50) (CATA1(I),I=23,33)
      WRITE (6,55)
      WRITE (6,60) (CATA1(I),I=34,41)
      WRITE (6,65)
      WRITE (6,70)
```

```
      WRITE (6,75) (DATA1(I),I=42,52)
      WRITE (6,80)
      WRITE (6,85) DATA1(53)
      WRITE (6,90)
      WRITE (6,95)
      WRITE (6,75) (DATA1(I),I=54,64)
      WRITE (6,100)
      WRITE (6,85)  DATA1(65)
      RETURN
      END
```

```
C**** CUMMY PLCT SUBRCUTINE                                          PLOT 001
      SUBRCUTINE FLCT (KCOMM,DATA1,IBRAN)                            PLOT 002
   10 FCRMAT ('1NC PLCTTING PROGRAM HAS BEEN INCLUDED,PLOT CPTION NOT PLOT 003
      AVAILABLE')                                                    PLOT 004
      WRITE (6,1C)                                                   PLOT 005
      RETURN                                                         PLOT 006
      ENC                                                            PLOT 007
```

APPENDIX A

```
C**** SUBROUTINE DIAG ****
C**** THIS SUBROUTINE PRINTS THE DIAGNOSTIC MESSAGES FOR THE ENTIRE
C**** PROGRAM
C
      SUBROUTINE DIAG (I,J,ITAB,IHPR,ITER1,ITER2,ITER4,ITER5,ITER6,
     1PAR1,PAR2,PARMN,PARMX)
   10 FORMAT ('1',48X,'DIAGNOSTIC ERROR MESSAGE'/53X,'CASE TERMINATED')
   15 FORMAT (//' ERROR IN INTERPOLATION SUBROUTINE TABIN,CALLED FROM MA
     1IN PROGRAM TO INTERPOLATE')
   20 FORMAT (//' ERROR IN INTERPOLATION SUBROUTINE TABP,CALLED FROM MAI
     1N PROGRAM TO INTERPOLATE')
   25 FORMAT (//' ERROR IN INTERPOLATION SUBROUTINE TABIN,CALLED FROM SU
     1BROUTINE PRATO TO INTERPOLATE')
   30 FORMAT (//' ERROR IN HYDROGEN PROPERTIES SUBROUTINE HPROP')
   35 FORMAT (//' NUMBER OF ITERATIONS EXCEEDS 30')
   50 FORMAT (' FOR MAIN TURBINE FLOW PARAMETER AS A FUNCTION OF MAIN TU
     1RBINE PRESSURE RATIO.')
   51 FORMAT (' PRESSURE RATIO IS LESS THAN MINIMUM TABULATED VALUE,POSS
     1IBLE SOLUTION IS TO EXTEND'/' MAIN TURBINE FLOW PARAMETER CURVE TO
     2 LOWER PRESSURE RATIOS.')
   55 FORMAT (' FOR MAIN TURBINE EFFICIENCY AS A FUNCTION OF MAIN TURBIN
     1E VELOCITY RATIO.')
   56 FORMAT (' VELOCITY RATIO IS LESS THAN MINIMUM TABULATED VALUE,POSS
     1IBLE SOLUTION IS TO EXTEND'/' MAIN TURBINE EFFICIENCY CURVE TO LOW
     2ER VELOCITY RATIOS.')
   57 FORMAT (' VELOCITY RATIO EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE
     1SOLUTION IS TO EXTEND'/' MAIN TURBINE EFFICIENCY CURVE TO HIGHER V
     2ELOCITY RATIOS.')
   60 FORMAT (' FOR INDUCER TURBINE FLOW PARAMETER AS A FUNCTION OF INDU
     1CER TURBINE PRESSURE RATIO.')
   61 FORMAT (' PRESSURE RATIO IS LESS THAN MINIMUM TABULATED VALUE,POSS
     1IBLE SOLUTION IS TO EXTEND'/' INDUCER TURBINE FLOW PARAMETER CURVE
     2 TO LOWER PRESSURE RATIOS.')
   70 FORMAT (' FOR INDUCER TURBINE EFFICIENCY AS A FUNCTION OF INDUCER
     1TURBINE VELOCITY RATIO.')
   71 FORMAT (' VELOCITY RATIO IS LESS THAN MINIMUM TABULATED VALUE,POSS
     1IBLE SOLUTION IS TO EXTEND'/' INDUCER TURBINE EFFICIENCY CURVE TO
     2LOWER VELOCITY RATIOS.')
   72 FORMAT (' VELOCITY RATIO EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE
     1SOLUTION IS TO EXTEND'/' INDUCER TURBINE EFFICIENCY CURVE TO HIGHE
     2R VELOCITY RATIOS.')
   75 FORMAT (' FOR INDUCER SHAFT SPEED AS A FUNCTION OF INDUCER POWER.'
     1)
   76 FORMAT (' INDUCER POWER IS LESS THAN MINIMUM TABULATED VALUE.')
   77 FORMAT (' POSSIBLE SOLUTION IS TO CHANGE INITIAL GUESS OF INDUCER
     1SPEED AND OR EXTEND RANGE OF INDUCER EFFICIENCY'/' AND HEAD RISE C
     2URVES.')
   80 FORMAT (' INDUCER POWER EXCEEDS MAXIMUM TABULATED VALUE.')
   85 FORMAT (  ' FOR INITIAL MAIN TURBINE INLET TOTAL TEMPERATURE AS A
     1FUNCTION OF TIME.')
   86 FORMAT (' INITIAL TIME IS LESS THAN MINIMUM TABULATED TIME.')
   87 FORMAT (' TURBINE INLET TEMPERATURE MUST BE TABULATED FOR INITIAL
     1TIME.')
   88 FORMAT (' INITIAL TIME EXCEEDS MAXIMUM TABULATED TIME.')
   90 FORMAT (' TURBINE INLET PRESSURE MUST BE TABULATED FOR INITIAL TIM
     1E IF TURBINE INLET PRESSURE OPTION IS BEING USED.')
   91 FORMAT (' TANK PRESSURE MUST BE TABULATED FOR INITIAL TIME.')
   92 FORMAT (' MAIN SHAFT SPEED MUST BE TABULATED FOR INITIAL TIME.')
   95 FORMAT (  ' FOR INITIAL MAIN TURBINE INLET TOTAL PRESSURE AS A FUN
     1CTION OF TIME.')
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 96 FORMAT (  ' FOR INITIAL MAIN SHAFT SPEED AS A FUNCTION OF TIME.')
 97 FORMAT (  ' FOR INITIAL TANK PRESSURE AS A FUNCTION OF TIME.')
 99 FORMAT (' FOR TURBINE INLET TEMPERATURE AS A FUNCTION OF TIME.')
100 FORMAT (' TIME EXCEEDS MAXIMUM TIME FOR WHICH TURBINE INLET TEMPER
   1ATURE IS TABULATED.')
104 FORMAT (' FOR TURBINE INLET PRESSURE AS A FUNCTION OF TIME.')
105 FORMAT (' TIME EXCEEDS MAXIMUM TIME FOR WHICH TURBINE INLET PRESSU
   1RE IS TABULATED.')
109 FORMAT (' FOR TANK PRESSURE AS A FUNCTION OF TIME.')
110 FORMAT (' TIME EXCEEDS MAXIMUM TIME FOR WHICH TANK PRESSURE IS TAB
   1ULATED.')
114 FORMAT (' FOR MAIN SHAFT SPEED AS A FUNCTION OF TIME.')
115 FORMAT (' TIME EXCEEDS MAXIMUM TIME FOR WHICH MAIN SHAFT SPEED IS
   1TABULATED.')
120 FORMAT (   ' FOR MAIN PUMP NORMALIZED HEAD RISE AS A FUNCTION OF Q
   1/N.')
121 FORMAT (' Q/N IS LESS THAN MINIMUM TABULATED VALUE,POSSIBLE SOLUTI
   1ON IS TO EXTEND'/' MAIN PUMP NORMALIZED HEAD RISE CURVES TO LOWER
   2Q/N.')
122 FORMAT (' Q/N EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE SOLUTION IS
   1 TO EXTEND'/' MAIN PUMP NORMALIZED HEAD RISE CURVES TO HIGHER Q/N.
   1')
125 FORMAT (' FOR MAIN PUMP EFFICIENCY AS A FUNCTION OF Q/N.')
126 FORMAT (' Q/N IS LESS THAN MINIMUM TABULATED VALUE,POSSIBLE SOLUTI
   1ON IS TO EXTEND'/' MAIN PUMP EFFICIENCY CURVES TO LOWER Q/N.')
127 FORMAT (' Q/N EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE SOLUTION IS
   1 TO EXTEND'/' MAIN PUMP EFFICIENCY CURVES TO HIGHER Q/N.')
130 FORMAT (  ' FOR INDUCER NORMALIZED HEAD RISE AS A FUNCTION OF Q/N.
   1')
131 FORMAT (' Q/N IS LESS THAN MINIMUM TABULATED VALUE,POSSIBLE SOLUTI
   1ON IS TO EXTEND'/' INDUCER NORMALIZED HEAD RISE CURVES TO LOWER Q/
   2N.')
132 FORMAT (' Q/N EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE SOLUTION IS
   1 TO EXTEND'/' INDUCER NORMALIZED HEAD RISE CURVES TO HIGHER Q/N.')
135 FORMAT (' FOR INDUCER EFFICIENCY AS A FUNCTION OF Q/N.')
136 FORMAT (' Q/N IS LESS THAN MINIMUM TABULATED VALUE,POSSIBLE SOLUTI
   1ON IS TO EXTEND'/' INDUCER EFFICIENCY CURVES TO LOWER Q/N.')
137 FORMAT (' Q/N EXCEEDS MAXIMUM TABULATED VALUE,POSSIBLE SOLUTION IS
   1 TO EXTEND'/' INDUCER EFFICIENCY CURVES TO HIGHER Q/N.')
150 FORMAT (//' PUMP INLET STATIC PRESSURE CORRECTION LOOP ITERATION C
   1OUNTER = ',I2/' LOOP STARTS AT STATEMENT 125 AND ENDS AT 154 IN MA
   2IN PROGRAM.')
151 FORMAT (//' MAIN SHAFT SPEED CORRECTION LOOP ITERATION COUNTER = '
   1,I2/' LOOP STARTS AT STATEMENT 120 AND ENDS AT 227 IN MAIN PROGRAM
   2.')
152 FORMAT (//' INDUCER SPEED CORRECTION LOOP ITERATION COUNTER = ',I2
   1/' LOOP STARTS AT STATEMENT 140 AND ENDS AT 650 IN MAIN PROGRAM.')
153 FORMAT (//' MAIN TURBINE PRESSURE RATIO REDUCTION LOOP ITERATION C
   1OUNTER = ',I2/' LOOP STARTS AT STATEMENT 200 AND ENDS AT 350 IN MA
   2IN PROGRAM.')
154 FORMAT (//' MAIN TURBINE PRESSURE RATIO CORRECTION LOOP ITERATION
   1COUNTER = ',I2/' LOOP STARTS AT STATEMENT 190 AND ENDS AT 450 IN M
   2AIN PROGRAM.')
160 FORMAT (//' PARAMETER VALUE = ',E13.6//' MINIMUM TABULATED PARAMET
   1ER VALUE = ',E13.6//' MAXIMUM TABULATED PARAMETER VALUE = ',E13.6)
170 FORMAT (' DURING SEARCH FOR SUCTION LINE SONIC VELOCITY.')
175 FORMAT (' DURING SEARCH FOR INDUCER INLET SPECIFIC VOLUME.')
180 FORMAT (' DURING SEARCH FOR PUMP INLET SPECIFIC VOLUME.')
190 FORMAT (/' PRESSURE IS LESS THAN MINIMUM TABLE VALUE.')
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191 FORMAT (/' PRESSURE IS GREATER THAN MAXIMUM TABLE VALUE.')         DIAG 119
192 FORMAT (/' TEMPERATURE IS BELOW THE FREEZING POINT.')              DIAG 120
193 FORMAT (/' TEMPERATURE IS GREATER THAN VAPOR TEMPERATURE.')        DIAG 121
196 FORMAT (/' PRESSURE = ',E13.6,' PSIA    TEMPERATURE = ',E13.6,' DEDIAG 122
   1G-R')                                                             DIAG 123
197 FORMAT (/' FREEZING POINT = ',E13.6,' DEG-R    VAPOR TEMPERATURE =DIAG 124
   1 ',E13.6,' DEG-R')                                                DIAG 125
195 FORMAT (/' MINIMUM TABULATED PRESSURE = ',E13.6,' PSIA   MAXIMUM TDIAG 126
   1ABULATED PRESSURE = ',E13.6,' PSIA')                              DIAG 127
    WRITE (6,10)                                                      DIAG 128
    GO TO (200,220,210,230,240),I                                     DIAG 129
200 WRITE (6,15)                                                      DIAG 130
    GO TO 300                                                         DIAG 131
210 WRITE (6,20)                                                      DIAG 132
    GO TO 300                                                         DIAG 133
220 WRITE (6,25)                                                      DIAG 134
    GO TO 300                                                         DIAG 135
230 WRITE (6,30)                                                      DIAG 136
    GO TO 600                                                         DIAG 137
240 WRITE (6,35)                                                      DIAG 138
    GO TO 550                                                         DIAG 139
300 GO TO (310,315,320,325,330,335,340,345,350,315,315,355,360,365,   DIAG 140
   1370,375,380,385,390),ITAB                                         DIAG 141
310 WRITE (6,50)                                                      DIAG 142
    WRITE (6,51)                                                      DIAG 143
    GO TO 500                                                         DIAG 144
315 WRITE (6,55)                                                      DIAG 145
    GO TO (316,316,317),J                                             DIAG 146
316 WRITE (6,56)                                                      DIAG 147
    GO TO 500                                                         DIAG 148
317 WRITE (6,57)                                                      DIAG 149
    GO TO 500                                                         DIAG 150
320 WRITE (6,60)                                                      DIAG 151
    WRITE (6,61)                                                      DIAG 152
    GO TO 500                                                         DIAG 153
325 WRITE (6,70)                                                      DIAG 154
    GO TO (326,326,327),J                                             DIAG 155
326 WRITE (6,71)                                                      DIAG 156
    GO TO 500                                                         DIAG 157
327 WRITE (6,72)                                                      DIAG 158
    GO TO 500                                                         DIAG 159
330 WRITE (6,120)                                                     DIAG 160
    GO TO (331,331,332),J                                             DIAG 161
331 WRITE (6,121)                                                     DIAG 162
    GO TO 500                                                         DIAG 163
332 WRITE (6,122)                                                     DIAG 164
    GO TO 500                                                         DIAG 165
335 WRITE (6,125)                                                     DIAG 166
    GO TO (336,336,337),J                                             DIAG 167
336 WRITE (6,126)                                                     DIAG 168
    GO TO 500                                                         DIAG 169
337 WRITE (6,127)                                                     DIAG 170
    GO TO 500                                                         DIAG 171
340 WRITE (6,130)                                                     DIAG 172
    GO TO (341,341,342),J                                             DIAG 173
341 WRITE (6,131)                                                     DIAG 174
    GO TO 500                                                         DIAG 175
342 WRITE (6,132)                                                     DIAG 176
    GO TO 500                                                         DIAG 177
345 WRITE (6,135)                                                     DIAG 178
```

```
      GO TO (346,346,347),J
  346 WRITE (6,136)
      GO TO 500
  347 WRITE (6,137)
      GO TO 500
  350 WRITE (6,75)
      GO TO (351,351,352),J
  351 WRITE (6,76)
      WRITE (6,77)
      GO TO 500
  352 WRITE (6,80)
      WRITE (6,77)
      GO TO 500
  355 WRITE (6,85)
      WRITE (6,87)
      GO TO (356,356,357),J
  356 WRITE (6,86)
      GO TO 500
  357 WRITE (6,88)
      GO TO 500
  360 WRITE (6,95)
      WRITE (6,90)
      GO TO (361,361,362),J
  361 WRITE (6,86)
      GO TO 500
  362 WRITE (6,88)
      GO TO 500
  365 WRITE (6,96)
      WRITE (6,92)
      GO TO (366,366,367),J
  366 WRITE (6,86)
      GO TO 500
  367 WRITE (6,88)
      GO TO 500
  370 WRITE (6,99)
      WRITE (6,100)
      GO TO 500
  375 WRITE (6,104)
      WRITE (6,105)
      GO TO 500
  380 WRITE (6,114)
      WRITE (6,115)
      GO TO 500
  385 WRITE (6,97)
      WRITE (6,91)
      GO TO (386,386,387),J
  386 WRITE (6,86)
      GO TO 500
  387 WRITE (6,88)
      GO TO 500
  390 WRITE (6,109)
      WRITE (6,110)
  500 WRITE (6,160) PAR1,PARMN,PARMX
  550 WRITE (6,150) ITER1
      WRITE (6,151) ITER2
      WRITE (6,152) ITER4
      WRITE (6,153) ITER5
      WRITE (6,154) ITER6
      GO TO 700
```

```
600 GO TO (610,620,630),IHPR                                          DIAG 238
610 WRITE (6,170)                                                     DIAG 239
    GO TO 640                                                         DIAG 240
620 WRITE (6,175)                                                     DIAG 241
    GO TO 640                                                         DIAG 242
630 WRITE (6,180)                                                     DIAG 243
640 GO TO (650,650,655,660,670),J                                     DIAG 244
650 WRITE (6,190)                                                     DIAG 245
    WRITE (6,195) PARMN,PARMX                                         DIAG 246
    GO TO 680                                                         DIAG 247
655 WRITE (6,191)                                                     DIAG 248
    WRITE (6,195) PARMN,PARMX                                         DIAG 249
    GO TO 680                                                         DIAG 250
660 WRITE (6,192)                                                     DIAG 251
    WRITE (6,197) PARMN,PARMX                                         DIAG 252
    GO TO 680                                                         DIAG 253
670 WRITE (6,193)                                                     DIAG 254
    WRITE (6,197) PARMN,PARMX                                         DIAG 255
680 WRITE (6,196) PAR1,PAR2                                           DIAG 256
700 RETURN                                                            DIAG 257
    END                                                               DIAG 258
```

APPENDIX B

HYDROGEN PROPERTIES DECK LISTING AND EXAMPLE CASE

Appendix B

The example case presented here is the six second transient case discussed in the program verification section of this report. The input data is for test -003 of the twin-spool test series. The data deck used for this case is shown on pages 341 and 342. The hydrogen properties deck completes this appendix.

Information shown on the computer output pages 295 through 340, is as follows:

<u>Page 295</u>

1. Identification of the eight characteristic turbopump component curves.
2. Main turbine flow parameter tabulated data (1)
3. Main turbine efficiency tabulated data (2)
4. Inducer turbine flow parameter tabulated data (3)
5. Inducer turbine efficiency tabulated data (4)

<u>Page 296</u>

Pump normalized head rise tabulated data (5)

<u>Page 297</u>

Pump efficiency tabulated data (6)

<u>Page 298</u>

Inducer normalized head rise tabulated data (7)

<u>Page 299</u>

Inducer efficiency tabulated data (8)

Appendix B

Page 300

Input case data including the four time dependent parameters.

The above six pages are simply a program listing of the input data.

The printing of computed data starts on page 301. Time is always listed as the first parameter.

Page 301

PSLI - Suction line inlet pressure
PII - Inducer inlet pressure
TII - Inducer inlet temperature
SVI - Inducer inlet specific volume
WSLI - Suction line inlet mass flow rate
QII - Inducer inlet volumetric flow rate
WI - Inducer inlet mass flow rate
PTII - Inducer inlet total pressure
NI - Inducer rotative speed
Q/NI - Inducer normalized flow rate
DPI - Inducer total pressure rise

Page 302

PTIE - Inducer discharge total pressure
PIE - Inducer discharge static pressure
DHI - Inducer head rise
DHI/N**2 - Inducer normalized head rise
NPSPI - Inducer net positive suction pressure
NPSHI - Inducer net positive suction head
NPSH/N**2 - Inducer normalized suction head

Appendix B

EATPI - Inducer efficiency

SHPI - Inducer power

TORQI - Inducer torque

Page 303

PMI - Pump inlet pressure

PTMI - Pump inlet total pressure

TMI - Pump inlet temperature

SVM - Pump inlet specific volume

QMI - Pump inlet volumetric flow rate

WP - Pump weight flow rate

NM - Pump speed

Q/NM - Pump normalized flow rate

DPM - Pump total pressure rise

PTME - Pump discharge total pressure

PML - Pump discharge static pressure

Page 304

DHM - Pump head rise

DHM/N**2 - Pump normalized head rise

NPSPM - Pump net positive suction pressure

NPSHM - Pump net positive suction head

NPSH/N**2 - Pump normalized suction head

EATPM - Pump efficiency

SHPM - Pump power

TORQM - Pump torque

Appendix B

Page 305

PTTII - Inducer turbine inlet total pressure

TTII - Inducer turbine inlet total temperature

PTEI - Inducer turbine discharge pressure

PRI - Inducer turbine total-to-static pressure ratio

WT - Turbine flow rate

FPI - Inducer turbine flow parameter

DHTI - Inducer turbine enthalpy drop

COI - Inducer turbine sporting velocity

UCOI - Inducer turbine velocity ratio

EATTI - Inducer turbine static efficiency

SHPTI - Inducer turbine power

Page 306

TORQIT - Inducer turbine torque

Page 307

PTTIM - Main turbine inlet total pressure

TTIM - Main turbine inlet total temperature

PTTEM - Main turbine discharge total pressure

PRM - Main turbine total-to-total pressure ratio

WT - Main turbine flow rate

FPM - Main turbine flow parameter

DHTM - Main turbine enthalpy drop

COM - Main turbine spouting velocity

UCOM - Main turbine velocity ratio

EATTM - Main turbine total efficiency

SHPTM - Main turbine power

TORQMT - Main turbine torque

For additional time points the data is printed on succeeding pages.

DATE 03-05-69 TWO-SPOOL TURBOPUMP PERFORMANCE PREDICTION PAGE 1

CURVES USED

1 MAIN TURBINE FLOW PARAMETER........FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69

2 MAIN TURBINE TOTAL EFFICIENCY......FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69

3 INDUCER TURBINE FLOW PARAMETER.....FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69

4 INDUCER TURBINE STATIC EFFICIENCY..FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69

5 MAIN PUMP HEAD RISE................FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69

6 MAIN PUMP EFFICIENCY...............FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69

7 INDUCER PUMP HEAD RISE.............FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69

8 INDUCER PUMP EFFICIENCY............FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69

MAIN TURBINE

(1) TOTAL PRESSURE RATIO	(1) FLOW PARAMETER	(2) VELOCITY RATIO U/CO	(2) TOTAL EFF.
1.000	0.0	0.0	0.0
1.100	0.315	0.0200	0.065
1.250	0.405	0.0400	0.130
1.500	0.490	0.0600	0.195
1.750	0.535	0.0800	0.260
2.000	0.568	0.1000	0.320
2.250	0.585	0.1200	0.377
2.500	0.600	0.1400	0.431
2.750	0.603	0.1600	0.479
3.000	0.605	0.1800	0.520
		0.2000	0.560
		0.2200	0.593
		0.2400	0.620
		0.2600	0.645
		0.2800	0.665
		0.3000	0.677

INDUCER TURBINE

(3) STATIC PRESSURE RATIO	(3) FLOW PARAMETER	(4) VELOCITY RATIO U/CO	(4) STATIC EFF.
1.000	0.0	0.0	0.0
1.100	0.870	0.0500	0.027
1.200	1.340	0.1000	0.056
1.300	1.620	0.1500	0.083
1.400	1.850	0.2000	0.110
1.500	2.010	0.2500	0.133
1.600	2.140	0.3000	0.155
1.700	2.250	0.3500	0.173
1.800	2.320	0.4000	0.187
1.900	2.390	0.4500	0.195
2.000	2.420	0.5000	0.197
2.100	2.440	0.5500	0.192
2.200	2.440	0.6000	0.177
		0.6500	0.150
		0.7000	0.107

CURVES USED

MAIN PUMP NORMALIZED HEAD RISE
(5)

NPSH/N2 FT/RPM2	0.500E-06	0.100E-05	0.200E-05
Q/N GAL/REV			
0.0	0.373E-04	0.398E-04	0.398E-04
0.040	0.380E-04	0.402E-04	0.402E-04
0.080	0.383E-04	0.405E-04	0.405E-04
0.100	0.383E-04	0.406E-04	0.406E-04
0.117	0.383E-04	0.406E-04	0.406E-04
0.121	0.455E-04	0.480E-04	0.480E-04
0.140	0.463E-04	0.485E-04	0.485E-04
0.160	0.465E-04	0.487E-04	0.487E-04
0.180	0.462E-04	0.486E-04	0.486E-04
0.200	0.457E-04	0.482E-04	0.482E-04
0.220	0.450E-04	0.478E-04	0.478E-04
0.240	0.440E-04	0.470E-04	0.470E-04
0.260	0.430E-04	0.459E-04	0.459E-04
0.280	0.418E-04	0.445E-04	0.445E-04
0.320	0.388E-04	0.415E-04	0.415E-04
0.360	0.339E-04	0.370E-04	0.370E-04
0.380	0.295E-04	0.335E-04	0.335E-04
0.400	0.205E-04	0.266E-04	0.285E-04
0.415	0.0	0.204E-04	0.236E-04
0.422	0.0	0.0	0.134E-04
0.424	0.0	0.0	0.0

CURVES USED

MAIN PUMP EFFICIENCY
(6)

NPSH/N2 FT/RPM2	C.500E-C6	C.100E-05	C.200E-05
C/N GAL/REV			
0.0	0.0	0.0	0.0
C.040	C.160	0.17C	0.170
C.080	0.315	0.325	0.325
C.100	0.383	0.356	0.396
0.117	0.440	0.456	0.456
0.121	0.465	0.5C0	0.500
C.140	C.518	0.533	0.533
0.160	0.548	0.564	0.564
0.180	0.575	0.591	0.591
C.200	0.596	0.613	0.613
0.220	0.611	0.626	0.626
0.240	0.618	0.632	0.632
0.260	0.618	0.631	0.631
C.280	0.611	0.625	0.625
0.320	0.588	0.604	0.604
0.360	0.537	0.561	0.561
0.380	0.471	C.501	0.510
0.40C	0.354	0.402	0.422
0.415	0.0	0.265	0.310
C.422	0.0	0.0	0.150
C.424	0.0	0.0	0.0

CURVES USED

INDUCER NORMALIZED HEAD RISE
(7)

NPSH/N2 FT/RPM2	0.0	0.450E-05
Q/N GAL/REV		
0.0	0.156E-04	0.161E-04
0.200	0.148E-04	0.154E-04
0.400	0.139E-04	0.145E-04
0.540	0.132E-04	0.138E-04
0.550	0.149E-04	0.156E-04
0.600	0.147E-04	0.154E-04
0.700	0.140E-04	0.146E-04
0.800	0.130E-04	0.134E-04
0.900	0.115E-04	0.119E-04
1.000	0.960E-05	0.102E-04
1.100	0.725E-05	0.820E-05
1.200	0.420E-05	0.540E-05
1.305	0.0	0.180E-05
1.350	0.0	0.0

CURVES USED

INDUCER EFFICIENCY
(8)

NPSH/N2 FT/RPM2	0.0	0.450E-05
Q/N GAL/REV		
0.0	0.0	0.0
0.200	0.150	0.160
0.400	0.280	0.300
0.540	0.355	0.390
0.550	0.415	0.450
0.600	0.450	0.484
0.700	0.496	0.530
0.800	0.527	0.560
0.900	0.544	0.575
1.000	0.531	0.567
1.100	0.475	0.525
1.200	0.367	0.440
1.305	0.0	0.220
1.350	0.0	0.0

INPUT CASE DATA

CONTROL FLAGS- IFLAG=1 JFLAG=2 KFLAG=2 JPRNT=1 JPLOT=0 NFLAG=*

INITIAL TIME	73.000SEC	FINAL TIME	84.950SEC
IND. TURBINE EXHAUST SYS. BACK PRESS.	14.7PSIA	ESTIMATED INITIAL INDUCER SPEED	500.0RPM
MAIN PUMP FLOW-SPEED RATIO,Q/N	0.320GAL/REV	TANK TEMPERATURE	37.6DEG R
SUCTION LINE DIAMETER	0.833FT	SUCTION LINE LENGTH	34.84FT
MAIN TURBINE MEAN BLADE RADIUS	5.445IN	INDUCER TURBINE MEAN BLADE RADIUS	5.260IN
MAIN ROTATING ASSY. MOMENT OF INERTIA	1.176LB-IN-SEC2	INDU. ROTATING ASSY. MOMENT OF INERTIA	0.813LB-IN-SEC2
INDUCER INLET AREA	78.50SQ-IN	PUMP INLET AREA	36.500SQ-IN
PUMP DISCHARGE AREA	17.720SQ-IN	TURBINE EXHAUST LINE LOSS COEFF.	0.0210
SUCTION LINE FRICTION FACTOR	0.0200		

TIME SEC	TURB. INLET TEMPERATURE DEG R	TIME SEC	TURB. INLET PRESSURE PSIA	TIME SEC	MAIN SHAFT SPEED RPM	TIME SEC	TANK PRESSURE PSIA
62.5072	443.3	62.5501	15.2	70.0000	1000.0	62.5168	32.7
72.5072	443.3	72.5501	15.2	86.0000	2000.0	72.5168	32.7
73.2784	443.6	73.2445	15.2			72.7484	32.6
74.0512	486.1	73.3219	20.6			72.8554	32.5
74.5134	510.1	73.5017	22.4			73.0052	32.7
75.5952	516.8	74.0167	36.4			73.4940	32.0
76.5212	523.6	74.5051	67.6			73.9834	31.9
77.5502	527.5	75.0457	69.6			75.0124	29.8
78.5274	530.4	75.5095	73.6			78.1904	24.3
80.0202	532.4	76.0235	96.5			80.0042	21.6
81.5124	533.6	77.0017	143.9			82.0114	21.0
82.5942	534.2	78.0051	206.5			84.0192	19.7
84.0352	535.3	79.0085	265.6			85.0220	16.7
85.0124	535.3	80.0119	294.2				
		80.5781	305.2				
		81.0931	312.8				
		82.0191	319.6				
		83.0225	329.9				
		84.0007	337.2				
		85.0041	337.0				

INDUCER AND SUCTION LINE

TIME SEC	PSLI PSIA	PII PSIA	TII DEG-R	SVI FT**3/LB	WSLI LB/SEC	QII GPM	WI LB/SEC	PTII PSIA	NI RPM	Q/NI GAL/REV	DPI PSI
73.0000	32.68	32.68	37.60	0.228	2.0	203.07	1.98	32.7	216.4	0.94	0.02
73.0500	32.62	32.61	37.60	0.228	2.0	203.07	1.98	32.6	216.4	0.94	0.02
73.1000	32.54	32.54	37.60	0.228	2.0	203.07	1.98	32.5	216.4	0.94	0.02
73.1500	32.47	32.47	37.60	0.228	2.0	203.07	1.98	32.5	216.4	0.94	0.02
73.2000	32.40	32.40	37.60	0.228	2.0	203.07	1.98	32.4	216.4	0.94	0.02
73.2499	32.33	32.33	37.60	0.228	2.0	203.07	1.98	32.3	216.4	0.94	0.02
73.2999	32.25	32.25	37.60	0.228	2.0	204.97	2.00	32.3	217.3	0.94	0.02
73.3499	32.18	32.18	37.60	0.228	2.2	229.81	2.24	32.2	226.6	1.01	0.02
73.3999	32.11	32.11	37.60	0.228	2.6	265.33	2.59	32.1	239.0	1.11	0.01
73.4499	32.04	32.04	37.60	0.228	3.0	303.29	2.96	32.0	252.2	1.20	0.01
73.4999	31.97	31.97	37.60	0.228	3.4	343.62	3.36	32.0	266.3	1.29	0.00
73.5499	31.96	31.96	37.60	0.228	3.8	386.23	3.77	32.0	281.4	1.37	0.0
73.5999	31.96	31.95	37.60	0.228	4.3	436.57	4.26	32.0	299.6	1.46	0.0
73.6498	31.95	31.95	37.60	0.228	4.8	494.22	4.83	31.9	320.3	1.54	0.0
73.6998	31.94	31.94	37.60	0.228	5.5	558.62	5.45	31.9	343.5	1.63	0.0
73.7498	31.93	31.93	37.60	0.228	6.1	629.51	6.15	31.9	369.3	1.70	0.0
73.7998	31.92	31.92	37.60	0.228	6.9	706.19	6.90	31.9	398.2	1.77	0.0
73.8498	31.91	31.91	37.60	0.228	7.7	787.92	7.69	31.9	430.1	1.83	0.0
73.8998	31.90	31.90	37.60	0.228	8.5	874.19	8.54	31.9	465.2	1.88	0.0
73.9498	31.89	31.88	37.60	0.228	9.4	964.50	9.42	31.9	503.4	1.92	0.0
73.9998	31.85	31.84	37.60	0.228	10.3	1058.25	10.33	31.9	544.9	1.94	0.0
74.0497	31.75	31.74	37.60	0.228	11.3	1154.49	11.27	31.8	589.4	1.96	0.0
74.0997	31.64	31.64	37.60	0.228	12.3	1259.62	12.30	31.6	639.7	1.97	0.0
74.1497	31.54	31.53	37.60	0.228	13.4	1376.41	13.44	31.5	697.5	1.97	0.0
74.1997	31.44	31.43	37.60	0.228	14.7	1502.84	14.67	31.4	763.3	1.97	0.0
74.2497	31.33	31.32	37.60	0.228	16.0	1637.09	15.98	31.3	837.6	1.95	0.0
74.2997	31.23	31.21	37.60	0.228	17.3	1776.75	17.35	31.2	920.3	1.93	0.0
74.3497	31.12	31.10	37.60	0.228	18.7	1919.80	18.74	31.1	1010.8	1.90	0.0
74.3997	31.02	31.00	37.60	0.228	20.2	2064.71	20.16	31.0	1109.2	1.86	0.0
74.4496	30.91	30.89	37.60	0.228	21.6	2209.68	21.57	30.9	1215.9	1.82	0.0
74.4996	30.81	30.78	37.60	0.228	23.0	2353.46	22.97	30.8	1330.8	1.77	0.0
74.5496	30.70	30.67	37.60	0.228	24.4	2494.97	24.36	30.7	1454.0	1.72	0.0
74.5996	30.60	30.55	37.60	0.228	25.6	2618.09	25.56	30.6	1578.3	1.66	0.0
74.6496	30.49	30.44	37.60	0.228	26.6	2722.76	26.58	30.5	1702.8	1.60	0.0
74.6996	30.38	30.33	37.60	0.228	27.4	2810.43	27.43	30.4	1827.6	1.54	0.0
74.7496	30.28	30.23	37.60	0.228	28.1	2883.36	28.15	30.3	1952.7	1.48	0.0
74.7996	30.17	30.12	37.60	0.228	28.7	2943.89	28.74	30.2	2078.0	1.42	0.0
74.8495	30.07	30.01	37.60	0.228	29.2	2994.06	29.23	30.1	2203.7	1.36	0.0
74.8995	29.97	29.91	37.60	0.228	29.6	3035.66	29.63	30.0	2329.8	1.30	0.31
74.9495	29.86	29.80	37.60	0.228	30.0	3070.39	29.97	29.9	2417.4	1.27	0.53
74.9995	29.76	29.70	37.60	0.228	30.3	3099.32	30.25	29.8	2494.4	1.24	0.75
75.0495	29.67	29.60	37.60	0.228	30.5	3123.55	30.49	29.7	2564.5	1.22	0.96
75.0995	29.58	29.51	37.60	0.228	30.7	3144.11	30.69	29.6	2629.6	1.20	1.16
75.1495	29.49	29.42	37.60	0.228	30.9	3162.99	30.87	29.5	2690.9	1.18	1.34
75.1995	29.40	29.33	37.60	0.228	31.0	3180.51	31.04	29.4	2746.9	1.16	1.51
75.2495	29.31	29.24	37.60	0.228	31.2	3196.93	31.20	29.3	2798.5	1.14	1.67
75.2994	29.22	29.15	37.60	0.228	31.4	3212.45	31.35	29.2	2846.3	1.13	1.82
75.3494	29.13	29.06	37.60	0.228	31.5	3227.25	31.50	29.1	2890.8	1.12	1.97
75.3994	29.04	28.97	37.60	0.228	31.6	3241.46	31.63	29.1	2932.2	1.11	2.10
75.4494	28.95	28.88	37.60	0.228	31.8	3255.19	31.77	29.0	2971.1	1.10	2.23

INDUCER AND SUCTION LINE

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TIME SEC	PTIE PSIA	PIE PSIA	DHI FT	DHI/N**2 FT/RPM**2	NPSPI PSI	NPSHI FT	NPSH/N**2 FT/RPM**2	EATPI	SHPI HP	TORQI FT-LB
73.0000	32.69	32.69	0.5	0.11293E-04	15.10	496.2	0.29279E-02	0.572	0.0	0.1
73.0500	32.63	32.63	0.5	0.11293E-04	15.04	494.2	0.10549E-01	0.572	0.0	0.1
73.1000	32.56	32.56	0.5	0.11293E-04	14.97	491.9	0.10499E-01	0.572	0.0	0.1
73.1500	32.49	32.49	0.5	0.11293E-04	14.90	489.5	0.10448E-01	0.572	0.0	0.1
73.2000	32.41	32.41	0.5	0.11293E-04	14.83	487.1	0.10398E-01	0.572	0.0	0.1
73.2499	32.34	32.34	0.5	0.11293E-04	14.75	484.8	0.10347E-01	0.572	0.0	0.1
73.2999	32.27	32.27	0.5	0.11206E-04	14.68	482.4	0.10215E-01	0.572	0.0	0.1
73.3499	32.20	32.20	0.5	0.99407E-05	14.61	480.0	0.93592E-02	0.561	0.0	0.1
73.3999	32.12	32.12	0.5	0.79108E-05	14.54	477.7	0.83549E-02	0.516	0.0	0.1
73.4499	32.05	32.05	0.3	0.53084E-05	14.47	475.3	0.74741E-02	0.434	0.0	0.1
73.4999	31.98	31.97	0.2	0.22997E-05	14.40	473.2	0.66734E-02	0.251	0.0	0.1
73.5499	31.96	31.96	0.0	0.0	14.39	472.9	0.59739E-02	1.000	0.0	0.0
73.5999	31.96	31.95	0.0	0.0	14.38	472.6	0.52655E-02	1.000	0.0	0.0
73.6498	31.95	31.94	0.0	0.0	14.37	472.3	0.46026E-02	1.000	0.0	0.0
73.6998	31.94	31.93	0.0	0.0	14.37	472.0	0.40002E-02	1.000	0.0	0.0
73.7498	31.93	31.91	0.0	0.0	14.36	471.7	0.34588E-02	1.000	0.0	0.0
73.7998	31.92	31.90	0.0	0.0	14.35	471.4	0.29733E-02	1.000	0.0	0.0
73.8498	31.91	31.89	0.0	0.0	14.34	471.1	0.25463E-02	1.000	0.0	0.0
73.8998	31.90	31.87	0.0	0.0	14.33	470.8	0.21759E-02	1.000	0.0	0.0
73.9498	31.89	31.86	0.0	0.0	14.32	470.5	0.18570E-02	1.000	0.0	0.0
73.9998	31.85	31.81	0.0	0.0	14.28	469.2	0.15805E-02	1.000	0.0	0.0
74.0497	31.75	31.70	0.0	0.0	14.18	465.9	0.13408E-02	1.000	0.0	0.0
74.0997	31.65	31.59	0.0	0.0	14.08	462.5	0.11301E-02	1.000	0.0	0.0
74.1497	31.55	31.48	0.0	0.0	13.97	459.2	0.94390E-03	1.000	0.0	0.0
74.1997	31.44	31.36	0.0	0.0	13.87	455.6	0.78241E-03	1.000	0.0	0.0
74.2497	31.34	31.24	0.0	0.0	13.77	452.4	0.64487E-03	1.000	0.0	0.0
74.2997	31.24	31.12	0.0	0.0	13.66	449.0	0.53021E-03	1.000	0.0	0.0
74.3497	31.13	31.00	0.0	0.0	13.56	445.6	0.43615E-03	1.000	0.0	0.0
74.3997	31.03	30.87	0.0	0.0	13.46	442.2	0.35944E-03	1.000	0.0	0.0
74.4496	30.92	30.75	0.0	0.0	13.35	438.8	0.29679E-03	1.000	0.0	0.0
74.4996	30.82	30.62	0.0	0.0	13.25	435.3	0.24581E-03	1.000	0.0	0.0
74.5496	30.71	30.49	0.0	0.0	13.14	431.9	0.20431E-03	1.000	0.0	0.0
74.5996	30.61	30.36	0.0	0.0	13.04	428.4	0.17199E-03	1.000	0.0	0.0
74.6496	30.50	30.23	0.0	0.0	12.93	425.0	0.14656E-03	1.000	0.0	0.0
74.6996	30.40	30.11	0.0	0.0	12.82	421.5	0.12619E-03	1.000	0.0	0.0
74.7496	30.29	29.99	0.0	0.0	12.72	418.1	0.10954E-03	1.000	0.0	0.0
74.7996	30.19	29.87	0.0	0.0	12.62	414.6	0.96021E-04	1.000	0.0	0.0
74.8495	30.08	29.76	0.0	0.0	12.51	411.2	0.84682E-04	1.000	0.0	0.0
74.8995	30.29	29.95	10.1	0.16692E-05	12.41	407.8	0.75140E-04	0.224	2.4	5.5
74.9495	30.41	30.07	17.5	0.29967E-05	12.31	404.5	0.69211E-04	0.293	3.3	7.1
74.9995	30.52	30.17	24.5	0.39422E-05	12.20	401.1	0.64465E-04	0.351	3.8	8.1
75.0495	30.64	30.28	31.5	0.47835E-05	12.11	398.0	0.60520E-04	0.402	4.3	8.9
75.0995	30.75	30.39	38.2	0.55220E-05	12.02	395.1	0.57131E-04	0.444	4.8	9.6
75.1495	30.84	30.48	44.1	0.60871E-05	11.93	392.1	0.54152E-04	0.461	5.4	10.5
75.1995	30.92	30.55	49.7	0.65801E-05	11.84	389.1	0.51573E-04	0.476	5.9	11.3
75.2495	30.99	30.62	54.9	0.70140E-05	11.75	386.2	0.49310E-04	0.489	6.4	12.0
75.2994	31.05	30.68	59.9	0.73983E-05	11.66	383.2	0.47304E-04	0.501	6.8	12.6
75.3494	31.11	30.73	64.7	0.77407E-05	11.57	380.3	0.45508E-04	0.511	7.2	13.2
75.3994	31.16	30.77	69.2	0.80470E-05	11.48	377.3	0.43885E-04	0.520	7.6	13.7
75.4494	31.19	30.80	73.2	0.82687E-05	11.39	374.4	0.42412E-04	0.527	8.0	14.2

MAIN PUMP

TIME SEC	PMI PSIA	PTMI PSIA	TMI DEG-R	SVM FT**3/LB	GMI GPM	WP LB/SEC	NM RPM	Q/NM GAL/REV	DPM PSI	PTME PSIA	PME PSIA
73.0000	32.69	32.69	37.60	0.228	203.1	1.98	634.6	0.320	0.51	33.20	33.19
73.0500	32.63	32.63	37.60	0.228	203.1	1.98	634.6	0.320	0.51	33.14	33.13
73.1000	32.56	32.56	37.60	0.228	203.1	1.98	634.6	0.320	0.51	33.07	33.06
73.1500	32.49	32.49	37.60	0.228	203.1	1.98	634.6	0.320	0.51	33.00	32.99
73.2000	32.41	32.41	37.60	0.228	203.1	1.98	634.6	0.320	0.51	32.92	32.92
73.2499	32.34	32.34	37.60	0.228	203.1	1.98	634.6	0.320	0.51	32.85	32.85
73.2999	32.27	32.27	37.60	0.228	205.0	2.00	640.5	0.320	0.52	32.79	32.78
73.3499	32.20	32.20	37.60	0.228	229.8	2.24	718.2	0.320	0.65	32.85	32.84
73.3999	32.12	32.12	37.60	0.228	265.3	2.59	829.2	0.320	0.87	32.99	32.98
73.4499	32.05	32.05	37.60	0.228	303.3	2.96	947.8	0.320	1.13	33.18	33.17
73.4999	31.97	31.98	37.60	0.228	343.6	3.36	1073.8	0.320	1.46	33.43	33.42
73.5499	31.96	31.96	37.60	0.228	386.2	3.77	1207.0	0.320	1.84	33.80	33.78
73.5999	31.95	31.96	37.60	0.228	436.6	4.26	1364.3	0.320	2.35	34.31	34.28
73.6498	31.94	31.95	37.60	0.228	494.2	4.83	1544.4	0.320	3.01	34.96	34.92
73.6998	31.93	31.94	37.60	0.228	558.6	5.45	1745.7	0.320	3.85	35.79	35.74
73.7498	31.91	31.93	37.60	0.228	629.5	6.15	1967.2	0.320	4.89	36.82	36.76
73.7998	31.90	31.92	37.60	0.228	706.2	6.90	2206.9	0.320	6.15	38.07	37.99
73.8498	31.89	31.91	37.60	0.228	787.9	7.69	2462.2	0.320	7.66	39.57	39.47
73.8998	31.87	31.90	37.60	0.228	874.2	8.54	2731.9	0.320	9.43	41.33	41.21
73.9498	31.86	31.89	37.60	0.228	964.5	9.42	3014.1	0.320	11.47	43.37	43.22
73.9998	31.81	31.85	37.60	0.228	1058.3	10.33	3307.0	0.320	13.81	45.66	45.49
74.0497	31.70	31.75	37.60	0.228	1154.5	11.27	3607.7	0.320	16.44	48.19	47.98
74.0997	31.59	31.65	37.60	0.228	1259.6	12.30	3936.3	0.320	19.57	51.22	50.97
74.1497	31.48	31.55	37.60	0.228	1376.4	13.44	4301.2	0.320	23.36	54.91	54.62
74.1997	31.36	31.44	37.60	0.228	1502.8	14.67	4696.3	0.320	27.85	59.30	58.95
74.2497	31.24	31.34	37.60	0.228	1637.1	15.98	5115.9	0.320	33.05	64.39	63.98
74.2997	31.12	31.24	37.60	0.228	1776.7	17.35	5552.3	0.320	38.93	70.17	69.68
74.3497	31.00	31.13	37.60	0.228	1919.8	18.74	5999.4	0.320	45.45	76.59	76.01
74.3997	30.87	31.03	37.60	0.228	2064.7	20.16	6452.2	0.320	52.57	83.60	82.94
74.4496	30.75	30.92	37.60	0.228	2209.7	21.57	6905.3	0.320	60.21	91.14	90.38
74.4996	30.62	30.82	37.60	0.228	2353.5	22.97	7354.6	0.320	68.30	99.12	98.26
74.5496	30.49	30.71	37.60	0.228	2495.0	24.36	7796.9	0.320	76.76	107.48	106.51
74.5996	30.36	30.61	37.60	0.228	2618.1	25.56	8181.6	0.320	84.52	115.13	114.07
74.6496	30.23	30.50	37.60	0.228	2722.8	26.58	8508.7	0.320	91.42	121.92	120.77
74.6996	30.11	30.40	37.60	0.228	2810.5	27.43	8782.7	0.320	97.40	127.79	126.57
74.7496	29.99	30.29	37.60	0.228	2883.4	28.15	9010.7	0.320	102.52	132.81	131.52
74.7996	29.87	30.19	37.60	0.228	2944.0	28.74	9199.9	0.320	106.86	137.05	135.71
74.8495	29.76	30.08	37.60	0.228	2994.1	29.23	9356.7	0.320	110.54	140.62	139.23
74.8995	29.95	30.29	37.60	0.228	3035.7	29.63	9486.7	0.320	113.63	143.92	142.49
74.9495	30.07	30.41	37.60	0.228	3070.3	29.97	9594.7	0.320	116.23	146.64	145.18
74.9995	30.17	30.52	37.60	0.228	3099.1	30.25	9684.8	0.320	118.43	148.95	147.46
75.0495	30.28	30.64	37.60	0.228	3123.3	30.49	9760.2	0.320	120.28	150.92	149.41
75.0995	30.39	30.75	37.60	0.228	3143.7	30.69	9824.1	0.320	121.86	152.62	151.08
75.1495	30.48	30.84	37.60	0.228	3162.5	30.87	9882.8	0.320	123.33	154.17	152.62
75.1995	30.55	30.92	37.60	0.228	3179.9	31.04	9937.3	0.320	124.69	155.61	154.04
75.2495	30.62	30.99	37.60	0.228	3196.3	31.20	9988.3	0.320	125.98	156.97	155.38
75.2994	30.68	31.05	37.60	0.228	3211.7	31.35	10036.6	0.320	127.20	158.25	156.65
75.3494	30.73	31.11	37.60	0.228	3226.4	31.50	10082.6	0.320	128.37	159.48	157.86
75.3994	30.77	31.16	37.60	0.228	3240.6	31.63	10126.8	0.320	129.50	160.65	159.02
75.4494	30.80	31.19	37.60	0.228	3254.2	31.77	10169.5	0.320	130.59	161.78	160.14

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MAIN PUMP

TIME SEC	DHM FT	DHM/N**2 FT/RPM**2	NPSPM PSI	NPSHM FT	NPSH/N**2 FT/RPM**2	EATPM	SHPM HP	TORQM FT-LB
73.0000	16.7	0.41500E-04	15.12	496.7	0.12334E-02	0.604	0.1	0.8
73.0500	16.7	0.41500E-04	15.06	494.7	0.12285E-02	0.604	0.1	0.8
73.1000	16.7	0.41500E-04	14.99	492.4	0.12227E-02	0.604	0.1	0.8
73.1500	16.7	0.41500E-04	14.91	490.0	0.12168E-02	0.604	0.1	0.8
73.2000	16.7	0.41500E-04	14.84	487.6	0.12109E-02	0.604	0.1	0.8
73.2499	16.7	0.41500E-04	14.77	485.3	0.12051E-02	0.604	0.1	0.8
73.2999	17.0	0.41500E-04	14.70	482.9	0.11771E-02	0.604	0.1	0.8
73.3499	21.4	0.41500E-04	14.63	480.5	0.93174E-03	0.604	0.1	1.1
73.3999	28.5	0.41500E-04	14.55	478.1	0.69546E-03	0.604	0.2	1.4
73.4499	37.3	0.41500E-04	14.48	475.6	0.52952E-03	0.604	0.3	1.8
73.4999	47.9	0.41500E-04	14.41	473.3	0.41052E-03	0.604	0.5	2.4
73.5499	60.5	0.41500E-04	14.39	472.9	0.32462E-03	0.604	0.7	3.0
73.5999	77.2	0.41500E-04	14.38	472.6	0.25392E-03	0.604	1.0	3.8
73.6498	99.0	0.41500E-04	14.37	472.3	0.19801E-03	0.604	1.4	4.9
73.6998	126.5	0.41500E-04	14.37	472.0	0.15489E-03	0.604	2.1	6.2
73.7498	160.6	0.41500E-04	14.36	471.7	0.12190E-03	0.604	3.0	7.9
73.7998	202.1	0.41500E-04	14.35	471.4	0.96800E-04	0.604	4.2	10.0
73.8498	251.6	0.41500E-04	14.34	471.1	0.77711E-04	0.604	5.8	12.4
73.8998	309.7	0.41500E-04	14.33	470.8	0.63088E-04	0.604	8.0	15.3
73.9498	377.0	0.41500E-04	14.32	470.5	0.51793E-04	0.604	10.7	18.6
73.9998	453.9	0.41500E-04	14.28	469.2	0.42903E-04	0.604	14.1	22.4
74.0497	540.2	0.41500E-04	14.18	465.9	0.35792E-04	0.604	18.3	26.7
74.0997	643.0	0.41500E-04	14.08	462.5	0.29851E-04	0.604	23.8	31.8
74.1497	767.8	0.41500E-04	13.97	459.2	0.24318E-04	0.604	31.1	37.9
74.1997	915.3	0.41500E-04	13.87	455.8	0.20666E-04	0.604	40.4	45.2
74.2497	1086.1	0.41500E-04	13.77	452.4	0.17288E-04	0.604	52.3	53.6
74.2997	1279.4	0.41500E-04	13.66	449.0	0.14565E-04	0.604	66.3	63.2
74.3497	1493.7	0.41500E-04	13.56	445.6	0.12361E-04	0.604	84.3	73.8
74.3997	1727.7	0.41500E-04	13.46	442.2	0.10622E-04	0.604	104.8	85.3
74.4496	1978.8	0.41500E-04	13.35	438.8	0.92023E-05	0.604	128.5	97.7
74.4996	2244.7	0.41500E-04	13.25	435.4	0.80466E-05	0.604	155.2	110.9
74.5496	2522.8	0.41500E-04	13.14	431.9	0.71048E-05	0.604	185.0	124.6
74.5996	2778.0	0.41500E-04	13.04	428.4	0.64003E-05	0.604	213.7	137.2
74.6496	3004.5	0.41500E-04	12.93	425.0	0.55897E-05	0.604	240.4	148.4
74.6996	3201.2	0.41500E-04	12.82	421.5	0.54545E-05	0.604	264.4	158.1
74.7496	3369.5	0.41500E-04	12.72	418.1	0.51492E-05	0.604	285.5	166.4
74.7996	3512.4	0.41500E-04	12.62	414.7	0.48992E-05	0.604	303.3	173.5
74.8495	3633.2	0.41500E-04	12.51	411.2	0.46975E-05	0.604	319.6	179.4
74.8995	3734.9	0.41500E-04	12.72	418.0	0.46446E-05	0.604	333.1	184.4
74.9495	3820.5	0.41500E-04	12.84	422.0	0.45837E-05	0.604	344.7	188.7
74.9995	3892.5	0.41500E-04	12.95	425.6	0.45376E-05	0.604	354.5	192.2
75.0495	3953.4	0.41500E-04	13.07	429.4	0.45081E-05	0.604	362.8	195.2
75.0995	4005.3	0.41500E-04	13.18	433.2	0.44884E-05	0.604	370.0	197.8
75.1495	4053.3	0.41500E-04	13.27	436.1	0.44651E-05	0.604	376.7	200.2
75.1995	4098.1	0.41500E-04	13.35	438.7	0.44427E-05	0.604	382.9	202.4
75.2495	4140.3	0.41500E-04	13.42	441.0	0.44206E-05	0.604	388.9	204.5
75.2994	4180.4	0.41500E-04	13.48	443.1	0.43984E-05	0.604	394.5	206.5
75.3494	4218.8	0.41500E-04	13.54	444.9	0.43759E-05	0.604	400.0	208.4
75.3994	4255.9	0.41500E-04	13.58	446.4	0.43529E-05	0.604	405.3	210.2
75.4494	4291.8	0.41500E-04	13.61	447.4	[illegible]	0.604	410.4	212.0

INDUCER TURBINE

TIME SEC	PTTII PSIA	TTII DEG-R	PTEI PSIA	PRI	WT LB/SEC	FPI	DHTI BTU/LB	COI FT/SEC	UCOI	EATTI	SHPTI HP
73.0000	14.82	443.1	14.70	1.008	0.05	0.073	0.0	428.8	0.023	0.013	0.0
73.0500	14.82	443.1	14.70	1.008	0.05	0.073	0.0	428.8	0.023	0.013	0.0
73.1000	14.82	443.1	14.70	1.008	0.05	0.073	0.0	428.8	0.023	0.013	0.0
73.1500	14.82	443.2	14.70	1.008	0.05	0.073	0.0	428.8	0.023	0.013	0.0
73.2000	14.82	443.2	14.70	1.008	0.05	0.073	0.0	428.8	0.023	0.013	0.0
73.2499	14.93	443.1	14.71	1.015	0.10	0.134	0.1	580.6	0.017	0.009	0.0
73.2999	15.58	443.6	14.78	1.055	0.35	0.475	0.1	1080.3	0.009	0.005	0.1
73.3499	15.78	446.0	14.81	1.065	0.42	0.568	0.1	1180.3	0.009	0.005	0.1
73.3999	15.83	448.5	14.82	1.068	0.44	0.592	0.1	1207.1	0.009	0.005	0.1
73.4499	15.88	450.9	14.84	1.071	0.46	0.615	0.2	1233.0	0.009	0.005	0.1
73.4999	15.94	453.3	14.85	1.073	0.48	0.639	0.2	1259.0	0.010	0.005	0.1
73.5499	16.09	455.6	14.88	1.081	0.53	0.705	0.2	1322.6	0.010	0.005	0.1
73.5999	16.23	457.7	14.92	1.088	0.58	0.765	0.2	1378.1	0.010	0.005	0.2
73.6498	16.36	459.8	14.95	1.094	0.63	0.820	0.2	1427.1	0.010	0.006	0.2
73.6998	16.51	461.8	14.99	1.101	0.67	0.875	0.3	1478.3	0.011	0.006	0.2
73.7498	16.71	463.7	15.03	1.112	0.72	0.925	0.3	1551.6	0.011	0.006	0.3
73.7998	16.91	465.6	15.08	1.122	0.76	0.972	0.3	1617.7	0.011	0.006	0.3
73.8498	17.10	467.3	15.12	1.131	0.80	1.017	0.4	1678.7	0.012	0.006	0.4
73.8998	17.30	469.0	15.17	1.141	0.85	1.061	0.4	1736.8	0.012	0.007	0.5
73.9498	17.50	470.6	15.22	1.150	0.89	1.106	0.4	1792.7	0.013	0.007	0.6
73.9998	17.69	472.2	15.27	1.159	0.93	1.146	0.5	1841.7	0.014	0.007	0.7
74.0497	18.03	473.5	15.36	1.174	1.01	1.218	0.6	1922.1	0.014	0.008	0.8
74.0997	18.47	474.5	15.49	1.192	1.11	1.304	0.6	2012.9	0.015	0.008	1.0
74.1497	18.97	475.4	15.62	1.214	1.20	1.380	0.7	2113.4	0.015	0.008	1.2
74.1997	19.51	476.1	15.76	1.238	1.29	1.446	0.8	2215.6	0.016	0.009	1.5
74.2497	20.04	476.7	15.90	1.260	1.38	1.508	1.0	2303.4	0.017	0.009	1.9
74.2997	20.53	477.2	16.04	1.279	1.47	1.562	1.1	2377.4	0.018	0.010	2.2
74.3497	21.02	477.6	16.19	1.298	1.55	1.614	1.2	2444.1	0.019	0.010	2.7
74.3997	21.54	478.0	16.34	1.318	1.64	1.661	1.4	2513.7	0.020	0.011	3.2
74.4456	22.06	478.4	16.50	1.337	1.72	1.705	1.6	2576.4	0.022	0.012	3.8
74.4956	22.57	478.7	16.66	1.355	1.80	1.747	1.7	2634.3	0.023	0.013	4.4
74.5496	22.64	477.8	16.68	1.358	1.82	1.753	1.9	2639.7	0.025	0.014	4.9
74.5996	22.66	476.5	16.68	1.358	1.82	1.754	2.1	2637.8	0.027	0.015	5.3
74.6496	22.67	475.6	16.69	1.359	1.82	1.755	2.2	2636.8	0.030	0.016	5.7
74.6996	22.69	474.9	16.69	1.359	1.83	1.756	2.4	2636.7	0.032	0.017	6.2
74.7456	22.71	474.4	16.70	1.360	1.83	1.758	2.5	2637.2	0.034	0.018	6.6
74.7956	22.73	474.0	16.71	1.360	1.84	1.759	2.7	2637.9	0.036	0.020	7.1
74.8495	22.75	473.7	16.71	1.361	1.84	1.761	2.9	2640.2	0.038	0.021	7.5
74.8995	22.77	473.6	16.72	1.362	1.84	1.763	3.0	2641.8	0.040	0.022	8.0
74.9495	22.80	473.5	16.73	1.363	1.85	1.765	3.2	2644.1	0.042	0.023	8.3
74.9995	22.83	473.5	16.74	1.364	1.85	1.767	3.3	2646.7	0.043	0.023	8.6
75.0495	22.85	473.6	16.75	1.365	1.86	1.769	3.4	2650.0	0.044	0.024	8.8
75.0995	22.92	473.6	16.77	1.367	1.87	1.775	3.5	2657.3	0.045	0.025	9.1
75.1495	22.99	473.7	16.79	1.369	1.88	1.780	3.5	2664.4	0.046	0.025	9.4
75.1995	23.06	473.9	16.81	1.372	1.89	1.785	3.6	2671.4	0.047	0.025	9.7
75.2495	23.13	474.0	16.83	1.374	1.90	1.790	3.7	2678.4	0.048	0.026	10.0
75.2994	23.20	474.1	16.85	1.376	1.91	1.795	3.8	2685.4	0.049	0.026	10.2
75.3494	23.26	474.3	16.88	1.379	1.92	1.801	3.9	2692.4	0.049	0.027	10.5
75.3994	23.33	474.4	16.90	1.381	1.93	1.806	3.9	2699.3	0.050	0.027	10.7
75.4494	23.40	474.6	16.92	1.383	1.94	1.810	4.0	2705.7	0.050	0.027	11.0

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INDUCER TURBINE

TIME SEC	TORQIT FT-LB
73.0000	0.1
73.0500	0.1
73.1000	0.1
73.1500	0.1
73.2000	0.1
73.2499	0.2
73.2999	1.4
73.3499	1.8
73.3999	2.0
73.4499	2.1
73.4999	2.2
73.5499	2.6
73.5999	2.9
73.6498	3.3
73.6998	3.7
73.7498	4.1
73.7998	4.5
73.8498	5.0
73.8998	5.4
73.9498	5.9
73.9998	6.3
74.0497	7.1
74.0997	8.2
74.1497	9.3
74.1997	10.5
74.2497	11.7
74.2997	12.8
74.3497	14.0
74.3997	15.1
74.4496	16.3
74.4996	17.5
74.5496	17.6
74.5996	17.7
74.6496	17.7
74.6996	17.7
74.7496	17.8
74.7996	17.8
74.8495	17.9
74.8995	17.9
74.9495	18.0
74.9995	18.0
75.0495	18.1
75.0995	18.3
75.1495	18.4
75.1995	18.6
75.2495	18.7
75.2994	18.9
75.3494	19.0
75.3994	19.2
75.4494	19.4

MAIN TURBINE

TIME SEC	PTTIM PSIA	TTIM DEG-R	PTTEM PSIA	PRM	WT LB/SEC	FPM	DHTM BTU/LB	COM FT/SEC	UCOM	EATTM	SHPTM HP
73.0000	15.16	443.5	14.82	1.023	0.05	0.071	1.4	702.0	0.043	0.140	0.1
73.0500	15.16	443.5	14.82	1.023	0.05	0.071	1.4	702.0	0.043	0.140	0.1
73.1000	15.16	443.5	14.82	1.023	0.05	0.071	1.4	702.0	0.043	0.140	0.1
73.1500	15.16	443.5	14.82	1.023	0.05	0.071	1.4	702.0	0.043	0.140	0.1
73.2000	15.16	443.5	14.82	1.023	0.05	0.071	1.4	702.0	0.043	0.140	0.1
73.2499	15.54	443.6	14.93	1.041	0.10	0.129	1.8	939.1	0.032	0.104	0.2
73.2999	19.06	444.8	15.58	1.223	0.35	0.389	4.1	2084.8	0.015	0.047	2.0
73.3499	20.89	447.5	15.78	1.323	0.42	0.430	5.4	2453.5	0.014	0.045	3.3
73.3999	21.38	450.3	15.83	1.350	0.44	0.439	6.5	2543.7	0.015	0.050	4.1
73.4499	21.87	453.0	15.88	1.377	0.46	0.448	7.7	2629.2	0.017	0.056	5.0
73.4999	22.36	455.8	15.94	1.403	0.48	0.457	9.0	2710.2	0.019	0.061	6.1
73.5499	23.70	458.5	16.09	1.473	0.53	0.481	10.8	2896.8	0.020	0.064	8.1
73.5999	25.06	461.3	16.23	1.544	0.58	0.498	12.9	3067.6	0.021	0.069	10.6
73.6498	26.42	464.0	16.36	1.615	0.63	0.511	15.3	3221.6	0.023	0.074	13.6
73.6998	27.79	466.7	16.51	1.683	0.67	0.523	18.1	3358.4	0.025	0.080	17.2
73.7498	29.15	469.5	16.71	1.744	0.72	0.534	21.1	3473.1	0.027	0.087	21.4
73.7998	30.52	472.2	16.91	1.805	0.76	0.542	24.4	3579.8	0.029	0.095	26.3
73.8498	31.88	475.0	17.10	1.864	0.80	0.550	27.9	3678.8	0.032	0.103	31.8
73.8998	33.25	477.7	17.30	1.922	0.85	0.558	31.8	3770.5	0.034	0.112	38.1
73.9498	34.61	480.5	17.50	1.978	0.89	0.565	35.8	3855.6	0.037	0.121	45.2
73.9998	35.98	483.2	17.69	2.034	0.93	0.570	40.2	3937.5	0.040	0.130	53.0
74.0497	38.55	486.0	18.03	2.138	1.01	0.577	45.3	4071.3	0.042	0.137	64.7
74.0997	41.74	488.6	18.47	2.260	1.11	0.586	51.2	4213.5	0.044	0.144	80.0
74.1497	44.93	491.2	18.97	2.369	1.20	0.592	57.4	4330.7	0.047	0.153	97.6
74.1997	48.12	493.8	19.51	2.466	1.29	0.598	64.2	4429.8	0.050	0.164	117.5
74.2497	51.31	496.4	20.04	2.561	1.38	0.601	71.3	4521.8	0.054	0.175	139.6
74.2997	54.49	499.0	20.53	2.655	1.47	0.602	78.9	4608.6	0.057	0.186	163.9
74.3497	57.68	501.6	21.02	2.745	1.55	0.603	86.7	4688.3	0.061	0.198	190.6
74.3997	60.87	504.2	21.54	2.826	1.64	0.604	94.7	4758.4	0.064	0.209	219.2
74.4496	64.06	506.8	22.06	2.904	1.72	0.604	102.7	4823.8	0.068	0.221	249.9
74.4996	67.25	509.4	22.57	2.979	1.80	0.605	110.8	4885.0	0.072	0.232	282.5
74.5496	67.76	510.4	22.64	2.993	1.81	0.605	117.8	4898.1	0.076	0.246	302.4
74.5996	67.95	510.8	22.66	2.999	1.82	0.605	123.7	4904.1	0.079	0.258	318.4
74.6496	68.13	511.2	22.67	3.005	1.82	0.605	128.6	4909.9	0.082	0.267	331.6
74.6996	68.32	511.6	22.69	3.011	1.83	0.605	132.6	4915.5	0.085	0.275	342.7
74.7496	68.50	512.0	22.71	3.017	1.83	0.605	135.9	4920.9	0.087	0.281	352.2
74.7996	68.69	512.4	22.73	3.022	1.84	0.605	138.7	4926.1	0.089	0.286	360.3
74.8495	68.87	512.8	22.75	3.027	1.84	0.605	141.1	4931.1	0.090	0.290	367.2
74.8995	69.06	513.2	22.77	3.032	1.84	0.605	143.0	4936.2	0.091	0.294	373.3
74.9495	69.24	513.6	22.80	3.037	1.85	0.605	144.7	4941.0	0.092	0.297	378.5
74.9995	69.43	514.0	22.83	3.042	1.85	0.605	146.1	4945.8	0.093	0.299	383.0
75.0495	69.63	514.4	22.85	3.047	1.86	0.605	147.3	4950.7	0.094	0.301	387.2
75.0995	70.07	514.8	22.92	3.057	1.87	0.605	148.5	4958.7	0.094	0.302	392.6
75.1495	70.51	515.2	22.99	3.067	1.88	0.605	149.6	4966.7	0.095	0.304	397.7
75.1995	70.94	515.6	23.06	3.076	1.89	0.605	150.6	4974.7	0.095	0.305	402.8
75.2495	71.38	516.0	23.13	3.086	1.90	0.605	151.6	4982.6	0.095	0.306	407.7
75.2994	71.82	516.4	23.20	3.096	1.91	0.605	152.5	4990.4	0.096	0.307	412.6
75.3494	72.25	516.8	23.26	3.106	1.92	0.605	153.4	4998.2	0.096	0.308	417.4
75.3994	72.69	517.2	23.33	3.115	1.93	0.605	154.3	5005.9	0.096	0.308	422.2
75.4494	73.13	517.7	23.40	3.125	1.94	0.605	155.2	5013.6	0.096	0.309	426.9

MAIN TURBINE

TIME SEC	TORQUE FT-LB
73.0000	0.8
73.0500	0.8
73.1000	0.8
73.1500	0.8
73.2000	0.8
73.2499	2.0
73.2999	16.6
73.3499	23.9
73.3999	25.6
73.4499	27.7
73.4999	29.7
73.5499	35.3
73.5999	40.8
73.6498	46.3
73.6998	51.8
73.7498	57.2
73.7998	62.5
73.8498	67.8
73.8998	73.3
73.9498	78.8
73.9998	84.2
74.0497	94.2
74.0997	106.8
74.1497	119.1
74.1997	131.4
74.2497	143.4
74.2997	155.1
74.3497	166.9
74.3997	178.4
74.4496	190.1
74.4996	201.8
74.5496	203.7
74.5996	204.4
74.6496	204.7
74.6996	204.9
74.7496	205.3
74.7996	205.7
74.8495	206.1
74.8995	206.6
74.9495	207.2
74.9995	207.7
75.0495	208.4
75.0995	209.9
75.1495	211.4
75.1995	212.9
75.2495	214.4
75.2994	215.9
75.3494	217.4
75.3994	219.0
75.4494	220.5

APPENDIX B

INDUCER AND SUCTION LINE

TIME SEC	PSLI PSIA	PII PSIA	TII DEG-R	SVI FT**3/LB	WSLI LB/SEC	QII GPM	WI LB/SEC	PTII PSIA	NI RPM	Q/NI GAL/REV	DPI PSI
75.4994	28.86	28.79	37.60	0.228	31.9	3268.52	31.90	28.9	3007.6	1.09	2.33
75.5494	28.77	28.70	37.60	0.228	32.0	3281.51	32.02	28.8	3042.3	1.08	2.43
75.5994	28.68	28.61	37.60	0.228	32.2	3302.30	32.23	28.7	3078.7	1.07	2.52
75.6494	28.59	28.51	37.60	0.228	32.5	3331.03	32.51	28.6	3118.2	1.07	2.62
75.6993	28.50	28.42	37.60	0.228	32.8	3365.91	32.85	28.5	3160.7	1.06	2.71
75.7493	28.40	28.33	37.60	0.228	33.2	3405.57	33.23	28.4	3206.0	1.06	2.80
75.7993	28.31	28.24	37.60	0.228	33.7	3448.90	33.66	28.3	3253.8	1.06	2.90
75.8493	28.22	28.14	37.60	0.228	34.1	3494.91	34.10	28.2	3304.3	1.06	3.01
75.8993	28.13	28.05	37.60	0.228	34.6	3542.93	34.57	28.1	3356.8	1.06	3.12
75.9493	28.04	27.95	37.60	0.228	35.1	3592.21	35.05	28.1	3411.3	1.05	3.24
75.9993	27.95	27.86	37.60	0.228	35.5	3642.24	35.54	28.0	3467.6	1.05	3.37
76.0493	27.85	27.77	37.60	0.228	36.0	3692.71	36.03	27.9	3525.3	1.05	3.50
76.0992	27.76	27.67	37.60	0.228	36.5	3743.71	36.53	27.8	3585.1	1.04	3.65
76.1492	27.67	27.58	37.60	0.228	37.0	3795.59	37.04	27.7	3646.6	1.04	3.80
76.1992	27.58	27.48	37.60	0.228	37.5	3847.95	37.55	27.6	3709.4	1.04	3.96
76.2492	27.48	27.39	37.60	0.228	38.1	3900.51	38.06	27.5	3773.5	1.03	4.13
76.2992	27.39	27.29	37.60	0.228	38.6	3953.03	38.57	27.4	3838.6	1.03	4.31
76.3492	27.30	27.20	37.60	0.228	39.1	4005.34	39.08	27.3	3904.4	1.03	4.50
76.3992	27.21	27.10	37.60	0.228	39.6	4057.33	39.59	27.2	3970.9	1.02	4.69
76.4492	27.11	27.01	37.60	0.228	40.1	4108.88	40.09	27.1	4037.8	1.02	4.90
76.4991	27.02	26.91	37.60	0.228	40.6	4159.86	40.59	27.0	4105.4	1.01	5.11
76.5491	26.93	26.81	37.60	0.228	41.1	4210.25	41.08	27.0	4173.2	1.01	5.32
76.5991	26.84	26.72	37.60	0.228	41.6	4260.05	41.56	26.9	4241.2	1.00	5.55
76.6491	26.74	26.62	37.60	0.228	42.0	4309.25	42.04	26.8	4309.1	1.00	5.78
76.6991	26.65	26.53	37.60	0.228	42.5	4357.87	42.52	26.7	4376.9	1.00	6.00
76.7491	26.56	26.43	37.60	0.228	43.0	4405.91	42.98	26.6	4444.1	0.99	6.23
76.7991	26.47	26.34	37.60	0.228	43.4	4453.31	43.45	26.5	4510.8	0.99	6.47
76.8491	26.37	26.24	37.60	0.228	43.9	4499.89	43.90	26.4	4576.9	0.98	6.70
76.8990	26.28	26.15	37.60	0.228	44.3	4545.77	44.35	26.3	4642.4	0.98	6.94
76.9490	26.19	26.05	37.60	0.228	44.8	4590.99	44.79	26.2	4707.1	0.98	7.18
76.9990	26.10	25.96	37.60	0.228	45.2	4635.60	45.22	26.1	4771.2	0.97	7.42
77.0490	26.00	25.86	37.60	0.228	45.6	4679.45	45.65	26.0	4835.2	0.97	7.67
77.0990	25.91	25.77	37.60	0.228	46.1	4726.14	46.10	25.9	4900.6	0.96	7.92
77.1490	25.82	25.67	37.60	0.228	46.6	4774.86	46.58	25.9	4967.3	0.96	8.17
77.1990	25.72	25.57	37.60	0.228	47.1	4824.83	47.06	25.8	5034.9	0.96	8.44
77.2490	25.63	25.48	37.60	0.228	47.6	4875.48	47.56	25.7	5103.4	0.96	8.71
77.2990	25.54	25.38	37.60	0.228	48.1	4926.43	48.05	25.6	5172.3	0.95	8.99
77.3489	25.45	25.29	37.60	0.228	48.6	4977.41	48.55	25.5	5241.7	0.95	9.27
77.3989	25.35	25.19	37.60	0.228	49.0	5028.25	49.05	25.4	5311.2	0.95	9.56
77.4489	25.26	25.09	37.60	0.228	49.5	5078.82	49.54	25.3	5380.8	0.94	9.85
77.4989	25.17	25.00	37.60	0.228	50.0	5129.03	50.03	25.2	5450.3	0.94	10.15
77.5489	25.07	24.90	37.60	0.228	50.5	5178.84	50.51	25.1	5519.5	0.94	10.46
77.5989	24.98	24.80	37.60	0.228	51.0	5228.23	50.99	25.0	5588.4	0.94	10.77
77.6489	24.89	24.71	37.60	0.228	51.5	5277.16	51.47	24.9	5657.0	0.93	11.08
77.6989	24.79	24.61	37.60	0.228	51.9	5325.41	51.94	24.8	5725.1	0.93	11.39
77.7488	24.70	24.51	37.60	0.228	52.4	5372.56	52.40	24.7	5792.7	0.93	11.71
77.7988	24.61	24.42	37.60	0.228	52.9	5418.84	52.85	24.6	5859.7	0.92	12.03
77.8488	24.51	24.32	37.60	0.228	53.3	5464.41	53.29	24.6	5926.2	0.92	12.35
77.8988	24.42	24.22	37.60	0.228	53.7	5509.40	53.73	24.5	5992.0	0.92	12.68
77.9488	24.33	24.13	37.60	0.228	54.2	5553.86	54.17	24.4	6057.2	0.92	13.00

INDUCER AND SUCTION LINE

TIME SEC	PTIE PSIA	PIE PSIA	DHI FT	DHI/N**2 FT/RPM**2	NPSPI PSI	NPSHI FT	NPSH/N**2 FT/RPM**2	EATPI	SHPI HP	TORQI FT-LB
75.4994	31.20	30.81	76.6	0.84691E-05	11.30	371.4	0.41061E-04	0.531	8.4	14.6
75.5494	31.21	30.82	79.9	0.86340E-05	11.21	368.5	0.39811E-04	0.534	8.7	15.0
75.5994	31.22	30.82	83.0	0.87554E-05	11.12	365.5	0.38567E-04	0.536	9.1	15.5
75.6494	31.22	30.81	86.0	0.88444E-05	11.03	362.6	0.37292E-04	0.538	9.4	15.9
75.6993	31.22	30.81	89.0	0.89118E-05	10.94	359.6	0.36000E-04	0.540	9.9	16.4
75.7493	31.22	30.80	92.2	0.89662E-05	10.85	356.7	0.34701E-04	0.541	10.3	16.9
75.7993	31.23	30.80	95.4	0.90127E-05	10.76	353.7	0.33407E-04	0.542	10.8	17.4
75.8493	31.25	30.80	98.9	0.90589E-05	10.67	350.7	0.32120E-04	0.543	11.3	18.0
75.8993	31.27	30.81	102.6	0.91047E-05	10.58	347.7	0.30856E-04	0.544	11.9	18.6
75.9493	31.30	30.83	106.5	0.91533E-05	10.48	344.7	0.29622E-04	0.545	12.5	19.2
75.9993	31.33	30.85	110.7	0.92074E-05	10.39	341.7	0.28418E-04	0.546	13.1	19.9
76.0493	31.38	30.88	115.2	0.92663E-05	10.30	338.7	0.27252E-04	0.547	13.8	20.5
76.0992	31.43	30.92	119.9	0.93320E-05	10.21	335.7	0.26117E-04	0.548	14.5	21.3
76.1492	31.49	30.97	125.0	0.94004E-05	10.12	332.7	0.25018E-04	0.550	15.3	22.0
76.1992	31.56	31.02	130.3	0.94720E-05	10.03	329.7	0.23958E-04	0.551	16.1	22.8
76.2492	31.64	31.09	135.9	0.95467E-05	9.93	326.6	0.22939E-04	0.553	17.0	23.7
76.2992	31.73	31.16	141.8	0.96246E-05	9.84	323.6	0.21964E-04	0.554	17.9	24.5
76.3492	31.82	31.24	147.9	0.97052E-05	9.75	320.6	0.21031E-04	0.556	18.9	25.4
76.3992	31.92	31.32	154.3	0.97879E-05	9.66	317.6	0.20141E-04	0.558	19.9	26.3
76.4492	32.03	31.42	161.0	0.98728E-05	9.57	314.6	0.19293E-04	0.560	21.0	27.3
76.4991	32.15	31.52	167.9	0.99608E-05	9.47	311.5	0.18484E-04	0.561	22.1	28.2
76.5491	32.28	31.63	175.0	0.10050E-04	9.38	308.5	0.17715E-04	0.563	23.2	29.2
76.5991	32.41	31.75	182.4	0.10140E-04	9.29	305.5	0.16984E-04	0.565	24.4	30.2
76.6491	32.55	31.87	189.9	0.10229E-04	9.20	302.5	0.16290E-04	0.567	25.6	31.2
76.6991	32.68	31.99	197.4	0.10305E-04	9.11	299.4	0.15631E-04	0.567	26.9	32.3
76.7491	32.82	32.11	205.0	0.10378E-04	9.01	296.4	0.15009E-04	0.568	28.2	33.3
76.7991	32.96	32.24	212.6	0.10449E-04	8.92	293.4	0.14419E-04	0.568	29.6	34.4
76.8491	33.10	32.36	220.4	0.10519E-04	8.83	290.4	0.13862E-04	0.568	30.9	35.5
76.8990	33.25	32.49	228.2	0.10588E-04	8.74	287.4	0.13333E-04	0.569	32.4	36.6
76.9490	33.40	32.63	236.1	0.10654E-04	8.65	284.3	0.12833E-04	0.569	33.8	37.7
76.9990	33.55	32.76	244.0	0.10719E-04	8.55	281.3	0.12357E-04	0.569	35.2	38.8
77.0490	33.70	32.90	252.1	0.10784E-04	8.46	278.3	0.11903E-04	0.570	36.7	39.9
77.0990	33.86	33.05	260.4	0.10842E-04	8.37	275.3	0.11462E-04	0.570	38.3	41.1
77.1490	34.02	33.19	268.8	0.10896E-04	8.28	272.3	0.11034E-04	0.570	39.9	42.2
77.1990	34.20	33.35	277.5	0.10948E-04	8.19	269.2	0.10620E-04	0.570	41.6	43.4
77.2490	34.37	33.51	286.4	0.10998E-04	8.09	266.2	0.10221E-04	0.571	43.4	44.7
77.2990	34.56	33.67	295.5	0.11046E-04	8.00	263.2	0.98363E-05	0.571	45.2	45.9
77.3489	34.75	33.85	304.9	0.11097E-04	7.91	260.1	0.94672E-05	0.571	47.1	47.2
77.3989	34.95	34.03	314.4	0.11146E-04	7.82	257.1	0.91131E-05	0.571	49.1	48.5
77.4489	35.15	34.21	324.1	0.11195E-04	7.72	254.0	0.87739E-05	0.571	51.1	49.9
77.4989	35.36	34.40	334.0	0.11244E-04	7.63	251.0	0.84492E-05	0.572	53.1	51.2
77.5489	35.57	34.59	344.0	0.11292E-04	7.54	247.9	0.81386E-05	0.572	55.2	52.6
77.5989	35.78	34.79	354.1	0.11339E-04	7.45	244.9	0.78416E-05	0.572	57.4	53.9
77.6489	36.00	34.99	364.3	0.11385E-04	7.35	241.9	0.75576E-05	0.572	59.6	55.3
77.6989	36.22	35.19	374.7	0.11431E-04	7.26	238.8	0.72860E-05	0.573	61.8	56.7
77.7488	36.45	35.40	385.1	0.11477E-04	7.17	235.8	0.70261E-05	0.573	64.1	58.1
77.7988	36.68	35.61	395.7	0.11524E-04	7.07	232.7	0.67776E-05	0.573	66.4	59.5
77.8488	36.91	35.82	406.3	0.11570E-04	6.98	229.7	0.65398E-05	0.573	68.7	60.9
77.8988	37.14	36.03	417.0	0.11615E-04	[illegible]	226.6	0.63122E-05	0.573	71.0	62.3
77.9488	37.37	36.25	427.6	0.11659E-04	[illegible]	[illegible]	0.60941E-05	0.574	73.4	63.7

MAIN PUMP

TIME SEC	PMI PSIA	PTMI PSIA	TMI DEG-R	SVM FT**3/LB	QMI GPM	WP LB/SEC	NM RPM	Q/NM GAL/REV	DPM PSI	PTME PSIA	PME PSIA
75.4994	30.81	31.20	37.60	0.228	3267.5	31.90	10210.9	0.320	131.66	162.86	161.21
75.5494	30.82	31.21	37.60	0.228	3280.4	32.02	10251.4	0.320	132.70	163.92	162.25
75.5994	30.82	31.22	37.60	0.228	3301.2	32.23	10316.2	0.320	134.39	165.60	163.91
75.6494	30.81	31.22	37.60	0.228	3329.8	32.51	10405.8	0.320	136.73	167.95	166.23
75.6993	30.81	31.22	37.60	0.228	3364.7	32.85	10514.6	0.320	139.61	170.83	169.07
75.7493	30.80	31.22	37.60	0.228	3404.3	33.23	10638.4	0.320	142.91	174.14	172.34
75.7993	30.80	31.23	37.60	0.228	3447.5	33.66	10773.6	0.320	146.57	177.80	175.96
75.8493	30.80	31.25	37.60	0.228	3493.5	34.10	10917.2	0.320	150.50	181.75	179.86
75.8993	30.81	31.27	37.60	0.228	3541.4	34.57	11067.0	0.320	154.66	185.93	183.99
75.9493	30.83	31.30	37.60	0.228	3590.7	35.05	11220.8	0.320	158.99	190.29	188.29
75.9993	30.85	31.33	37.60	0.228	3640.6	35.54	11376.9	0.320	163.45	194.78	192.72
76.0493	30.88	31.38	37.60	0.228	3691.0	36.03	11534.3	0.320	168.00	199.38	197.26
76.0992	30.92	31.43	37.60	0.228	3741.9	36.53	11693.4	0.320	172.67	204.10	201.93
76.1492	30.97	31.49	37.60	0.228	3793.7	37.04	11855.2	0.320	177.48	208.97	206.74
76.1992	31.02	31.56	37.60	0.228	3845.9	37.55	12018.5	0.320	182.41	213.97	211.67
76.2492	31.09	31.64	37.60	0.228	3898.4	38.06	12182.4	0.320	187.42	219.06	216.70
76.2992	31.16	31.73	37.60	0.228	3950.8	38.57	12346.1	0.320	192.49	224.22	221.80
76.3492	31.24	31.82	37.60	0.228	4003.0	39.08	12509.2	0.320	197.61	229.43	226.95
76.3992	31.32	31.92	37.60	0.228	4054.8	39.59	12671.3	0.320	202.76	234.69	232.14
76.4492	31.42	32.03	37.60	0.228	4106.2	40.09	12831.9	0.320	207.94	239.98	237.36
76.4991	31.52	32.15	37.60	0.228	4157.0	40.59	12990.7	0.320	213.12	245.28	242.60
76.5491	31.63	32.28	37.60	0.228	4207.3	41.08	13147.7	0.320	218.31	250.59	247.84
76.5991	31.75	32.41	37.60	0.228	4256.9	41.56	13302.8	0.320	223.49	255.90	253.09
76.6491	31.87	32.55	37.60	0.228	4305.9	42.04	13456.0	0.320	228.68	261.22	258.35
76.6991	31.99	32.68	37.60	0.228	4354.4	42.52	13607.4	0.320	233.85	266.54	263.60
76.7491	32.11	32.82	37.60	0.228	4402.2	42.98	13756.9	0.320	239.03	271.85	268.84
76.7991	32.24	32.96	37.60	0.228	4449.4	43.45	13904.4	0.320	244.19	277.15	274.08
76.8491	32.36	33.10	37.60	0.228	4495.8	43.90	14049.4	0.320	249.31	282.41	279.28
76.8990	32.49	33.25	37.60	0.228	4541.5	44.35	14192.2	0.320	254.41	287.66	284.46
76.9490	32.63	33.40	37.60	0.228	4586.5	44.79	14332.9	0.320	259.48	292.88	289.62
76.9990	32.76	33.55	37.60	0.228	4630.9	45.22	14471.6	0.320	264.54	298.08	294.76
77.0490	32.90	33.70	37.60	0.228	4674.6	45.65	14608.0	0.320	269.55	303.25	299.86
77.0990	33.05	33.86	37.60	0.228	4721.0	46.10	14753.2	0.320	274.94	308.80	305.35
77.1490	33.19	34.02	37.60	0.228	4769.5	46.58	14904.8	0.320	280.63	314.65	311.12
77.1990	33.35	34.20	37.60	0.228	4819.2	47.06	15060.2	0.320	286.52	320.71	317.11
77.2490	33.51	34.37	37.60	0.228	4869.7	47.56	15217.7	0.320	292.55	326.92	323.25
77.2990	33.67	34.56	37.60	0.228	4920.3	48.05	15376.1	0.320	298.68	333.24	329.48
77.3489	33.85	34.75	37.60	0.228	4971.1	48.55	15534.6	0.320	304.88	339.63	335.80
77.3989	34.03	34.95	37.60	0.228	5021.6	49.05	15692.6	0.320	311.12	346.07	342.16
77.4489	34.21	35.15	37.60	0.228	5071.9	49.54	15849.7	0.320	317.39	352.54	348.55
77.4989	34.40	35.36	37.60	0.228	5121.8	50.03	16005.7	0.320	323.68	359.04	354.97
77.5489	34.59	35.57	37.60	0.228	5171.3	50.51	16160.5	0.320	329.98	365.55	361.40
77.5989	34.79	35.78	37.60	0.228	5220.4	50.99	16313.8	0.320	336.28	372.06	367.84
77.6489	34.99	36.00	37.60	0.228	5269.0	51.47	16465.8	0.320	342.58	378.59	374.28
77.6989	35.19	36.22	37.60	0.228	5317.0	51.94	16615.6	0.320	348.86	385.08	380.69
77.7488	35.40	36.45	37.60	0.228	5363.8	52.40	16761.9	0.320	355.04	391.49	387.02
77.7988	35.61	36.68	37.60	0.228	5409.7	52.85	16905.5	0.320	361.16	397.84	393.30
77.8488	35.82	36.91	37.60	0.228	5455.0	53.29	17046.8	0.320	367.24	404.15	399.53
77.8988	36.03	37.14	37.60	0.228	5499.6	53.73	17186.3	0.320	373.29	410.43	405.73
77.9488	36.25	37.37	37.60	0.228	5543.7	54.17	17324.2	0.320	379.31	416.69	411.92

APPENDIX B

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MAIN PUMP

TIME SEC	DHM FT	DHM/N**2 FT/RPM**2	NPSPM PSI	NPSHM FT	NPSH/N**2 FT/RPM**2	EATPN	SHPM HP	TORQM FT-LB
75.4994	4326.9	0.41500E-04	13.63	447.9	0.42959E-05	0.604	415.5	213.7
75.5494	4361.2	0.41500E-04	13.64	448.2	0.42653E-05	0.604	420.4	215.4
75.5994	4416.6	0.41500E-04	13.64	448.4	0.42132E-05	0.604	428.5	218.1
75.6494	4493.6	0.41500E-04	13.65	448.4	0.41414E-05	0.604	439.7	221.9
75.6993	4588.1	0.41500E-04	13.65	448.5	0.40567E-05	0.604	453.7	226.6
75.7493	4696.7	0.41500E-04	13.65	448.7	0.39642E-05	0.604	469.9	232.0
75.7993	4816.9	0.41500E-04	13.66	448.9	0.38677E-05	0.604	488.0	237.9
75.8493	4946.2	0.41500E-04	13.68	449.4	0.37708E-05	0.604	507.8	244.3
75.8993	5082.9	0.41500E-04	13.70	450.1	0.36750E-05	0.604	529.0	251.0
75.9493	5225.1	0.41500E-04	13.72	451.0	0.35822E-05	0.604	551.3	258.1
75.9993	5371.5	0.41500E-04	13.76	452.2	0.34937E-05	0.604	574.7	265.3
76.0493	5521.2	0.41500E-04	13.80	453.6	0.34098E-05	0.604	598.9	272.7
76.0992	5674.6	0.41500E-04	13.86	455.4	0.33305E-05	0.604	624.0	280.3
76.1492	5832.7	0.41500E-04	13.92	457.4	0.32547E-05	0.604	650.3	288.1
76.1992	5994.5	0.41500E-04	13.99	459.7	0.31829E-05	0.604	677.5	296.1
76.2492	6159.1	0.41500E-04	14.07	462.3	0.31152E-05	0.604	705.6	304.2
76.2992	6325.7	0.41500E-04	14.15	465.2	0.30513E-05	0.604	734.5	312.4
76.3492	6493.9	0.41500E-04	14.25	468.3	0.29925E-05	0.604	763.9	320.8
76.3992	6663.3	0.41500E-04	14.35	471.6	0.29373E-05	0.604	794.0	329.1
76.4492	6833.3	0.41500E-04	14.46	475.2	0.28861E-05	0.604	824.6	337.5
76.4991	7003.5	0.41500E-04	14.58	479.1	0.28389E-05	0.604	855.[illegible]	345.9
76.5491	7173.8	0.41500E-04	14.70	483.2	0.27953E-05	0.604	887.0	354.3
76.5991	7344.0	0.41500E-04	14.84	487.5	0.27549E-05	0.604	918.8	362.8
76.6491	7514.2	0.41500E-04	14.97	492.0	0.27174E-05	0.604	951.0	371.2
76.6991	7684.2	0.41500E-04	15.11	496.4	0.26812E-05	0.604	983.4	379.6
76.7491	7854.0	0.41500E-04	15.25	501.0	0.26471E-05	0.604	1016.2	388.0
76.7991	8023.3	0.41500E-04	15.39	505.6	0.26151E-05	0.604	1049.3	396.4
76.8491	8191.5	0.41500E-04	15.53	510.3	0.25852E-05	0.604	1082.5	404.7
76.8990	8358.8	0.41500E-04	15.68	515.1	0.25571E-05	0.604	1115.8	412.9
76.9490	8525.4	0.41500E-04	15.82	519.9	0.25307E-05	0.604	1149.4	421.2
76.9990	8691.2	0.41500E-04	15.97	524.8	0.25058E-05	0.604	1182.1	429.4
77.0490	8855.8	0.41500E-04	16.13	529.9	0.24830E-05	0.604	121[illegible]	437.5
77.0990	9032.8	0.41500E-04	16.29	535.1	0.24584E-05	0.604	1253.6	446.3
77.1490	9219.3	0.41500E-04	16.45	540.5	0.24330E-05	0.604	129[illegible].6	455.5
77.1990	9412.5	0.41500E-04	16.62	546.1	0.24078E-05	0.604	1333.5	465.1
77.2490	9610.5	0.41500E-04	16.80	552.0	0.23835E-05	0.604	1375.9	474.9
77.2990	9811.6	0.41500E-04	16.99	558.0	0.23603E-05	0.604	1419.3	484.8
77.3489	10014.9	0.41500E-04	17.16	564.3	0.23383E-05	0.604	1463.7	494.9
77.3989	10219.7	0.41500E-04	17.38	570.8	0.23177E-05	0.604	1508.9	505.0
77.4489	10425.4	0.41500E-04	17.58	577.4	0.22984E-05	0.604	1554.7	515.2
77.4989	10631.6	0.41500E-04	17.78	584.2	0.22803E-05	0.604	1601.1	525.4
77.5489	10838.2	0.41500E-04	18.00	591.1	0.22633E-05	0.604	1648.0	535.6
77.5989	11044.9	0.41500E-04	18.21	598.1	0.22474E-05	0.604	1695.4	545.8
77.6489	11251.6	0.41500E-04	18.43	605.3	0.22324E-05	0.604	1743.3	556.1
77.6989	11457.2	0.41500E-04	18.65	612.5	0.22186E-05	0.604	1791.4	565.2
77.7488	11659.8	0.41500E-04	18.88	619.9	0.22063E-05	0.604	1839.2	576.3
77.7988	11860.5	0.41500E-04	19.10	627.4	0.21951E-05	0.604	1886.9	586.2
77.8488	12059.7	0.41500E-04	19.33	634.9	0.21849E-05	0.604	1934.7	596.1
77.8988	12257.9	0.41500E-04	19.57	642.9	0.21753E-05	0.604	1982.7	605.9
77.9488	12455.3	0.41500E-04	19.80	650.2	0.21663E-05	0.604	2030.[illegible]	615.7

INDUCER TURBINE

TIME SEC	PTTII PSIA	TTII DEG-R	PTEI PSIA	PRI	WT LB/SEC	FPI	DHTI BTU/LB	COI FT/SEC	UCOI	EATTI	SHPTI HP
75.4994	23.47	474.8	16.94	1.385	1.96	1.816	4.0	2712.9	0.051	0.028	11.2
75.5494	23.76	474.8	17.04	1.394	2.00	1.836	4.1	2738.3	0.051	0.028	11.7
75.5994	24.14	474.6	17.16	1.407	2.06	1.861	4.2	2773.4	0.051	0.028	12.3
75.6494	24.54	474.3	17.29	1.420	2.12	1.881	4.3	2807.6	0.051	0.028	13.0
75.6993	24.93	473.9	17.41	1.432	2.18	1.902	4.5	2840.4	0.051	0.028	13.7
75.7493	25.32	473.5	17.53	1.444	2.24	1.921	4.6	2870.4	0.051	0.028	14.4
75.7993	25.73	473.0	17.66	1.457	2.30	1.941	4.7	2901.0	0.051	0.028	15.2
75.8493	26.11	472.5	17.78	1.468	2.35	1.959	4.8	2927.8	0.052	0.028	16.0
75.8993	26.50	472.0	17.91	1.479	2.41	1.977	4.9	2953.3	0.052	0.028	16.8
75.9493	26.89	471.5	18.04	1.491	2.47	1.995	5.0	2978.6	0.053	0.028	17.6
75.9993	27.28	470.9	18.17	1.501	2.53	2.012	5.2	3002.2	0.053	0.029	18.5
76.0493	27.72	470.4	18.31	1.514	2.59	2.028	5.3	3029.7	0.053	0.029	19.5
76.0992	28.16	469.9	18.45	1.526	2.65	2.044	5.5	3055.1	0.054	0.029	20.5
76.1492	28.60	469.3	18.60	1.538	2.72	2.059	5.6	3079.1	0.054	0.030	21.5
76.1992	29.03	468.8	18.75	1.549	2.78	2.073	5.7	3101.9	0.055	0.030	22.6
76.2492	29.47	468.2	18.89	1.560	2.84	2.088	5.9	3123.5	0.055	0.030	23.6
76.2992	29.90	467.6	19.04	1.570	2.91	2.102	6.0	3144.1	0.056	0.031	24.8
76.3492	30.34	467.1	19.19	1.581	2.97	2.115	6.2	3163.8	0.057	0.031	25.9
76.3992	30.77	466.5	19.34	1.591	3.03	2.128	6.3	3182.8	0.057	0.031	27.1
76.4492	31.22	466.0	19.50	1.602	3.10	2.142	6.5	3202.3	0.058	0.032	28.3
76.4991	31.67	465.5	19.65	1.612	3.16	2.153	6.6	3221.0	0.059	0.032	29.6
76.5491	32.12	464.9	19.80	1.622	3.22	2.164	6.8	3238.7	0.059	0.032	30.9
76.5991	32.56	464.4	19.96	1.632	3.29	2.175	6.9	3255.6	0.060	0.033	32.2
76.6491	33.01	463.8	20.11	1.641	3.35	2.185	7.1	3271.7	0.060	0.033	33.5
76.6991	33.45	463.2	20.27	1.650	3.41	2.195	7.2	3287.2	0.061	0.033	34.8
76.7491	33.90	462.7	20.43	1.659	3.48	2.205	7.4	3302.1	0.062	0.034	36.2
76.7991	34.34	462.2	20.58	1.668	3.54	2.215	7.5	3316.4	0.062	0.034	37.6
76.8491	34.78	461.7	20.74	1.677	3.60	2.225	7.7	3330.2	0.063	0.035	39.0
76.8990	35.22	461.2	20.90	1.685	3.66	2.234	7.8	3343.5	0.064	0.035	40.5
76.9490	35.67	460.7	21.06	1.694	3.73	2.243	8.0	3356.7	0.064	0.035	41.9
76.9990	36.15	460.2	21.22	1.703	3.79	2.252	8.1	3371.7	0.065	0.036	43.5
77.0490	36.76	459.8	21.43	1.715	3.88	2.261	8.3	3390.7	0.065	0.036	45.3
77.0990	37.37	459.3	21.64	1.727	3.96	2.269	8.4	3408.8	0.066	0.036	47.1
77.1490	37.98	458.7	21.85	1.738	4.04	2.277	8.6	3425.9	0.067	0.037	49.0
77.1990	38.59	458.2	22.06	1.749	4.12	2.285	8.7	3442.2	0.067	0.037	50.9
77.2490	39.20	457.7	22.27	1.760	4.20	2.292	8.9	3457.6	0.068	0.037	52.9
77.2990	39.81	457.1	22.49	1.770	4.28	2.299	9.1	3472.2	0.068	0.038	54.9
77.3489	40.42	456.6	22.70	1.781	4.36	2.306	9.2	3486.2	0.069	0.038	57.0
77.3989	41.02	456.0	22.91	1.790	4.44	2.313	9.4	3499.6	0.070	0.038	59.1
77.4489	41.63	455.5	23.13	1.800	4.53	2.320	9.6	3512.4	0.070	0.039	61.2
77.4989	42.23	454.9	23.34	1.809	4.61	2.326	9.7	3524.6	0.071	0.039	63.3
77.5489	42.83	454.4	23.56	1.818	4.69	2.333	9.9	3536.3	0.072	0.040	65.5
77.5989	43.43	453.8	23.77	1.827	4.77	2.339	10.0	3547.5	0.072	0.040	67.7
77.6489	44.04	453.3	23.99	1.836	4.85	2.345	10.2	3558.2	0.073	0.040	70.0
77.6989	44.64	452.8	24.21	1.844	4.93	2.351	10.4	3568.7	0.074	0.041	72.2
77.7488	45.24	452.4	24.42	1.852	5.01	2.357	10.5	3578.9	0.074	0.041	74.5
77.7988	45.84	451.9	24.64	1.860	5.09	2.362	10.7	3588.7	0.075	0.041	76.9
77.8488	46.44	451.5	24.86	1.868	5.18	2.368	10.8	3598.1	0.076	0.042	79.2
77.8988	47.04	451.0	25.08	1.876	5.26	2.373	11.0	3607.2	0.076	0.042	81.6
77.9488	47.64	450.6	25.30	1.883	5.34	2.378	11.1	3616.0	0.077	0.043	84.0

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INDUCER TURBINE

TIME SEC	TORQIT FT-LB
75.4994	19.5
75.5494	20.2
75.5994	21.1
75.6494	21.9
75.6993	22.8
75.7493	23.6
75.7993	24.6
75.8493	25.4
75.8993	26.3
75.9493	27.2
75.9993	28.0
76.0493	29.0
76.0992	30.0
76.1492	31.0
76.1992	31.9
76.2492	32.9
76.2992	33.9
76.3492	34.9
76.3992	35.8
76.4492	36.9
76.4991	37.8
76.5491	38.8
76.5991	39.8
76.6491	40.8
76.6991	41.8
76.7491	42.8
76.7991	43.8
76.8491	44.8
76.8990	45.8
76.9490	46.8
76.9990	47.9
77.0490	49.2
77.0990	50.5
77.1490	51.8
77.1990	53.1
77.2490	54.5
77.2990	55.8
77.3489	57.1
77.3989	58.4
77.4489	59.7
77.4989	61.0
77.5489	62.3
77.5989	63.7
77.6489	65.0
77.6989	66.3
77.7488	67.6
77.7988	68.9
77.8488	70.2
77.8988	71.5
77.9488	72.8

MAIN TURBINE

TIME SEC	PTTIM PSIA	TTIM DEG-R	PTTEM PSIA	PRM	WT LB/SEC	PPM	DHTM BTU/LB	CUM FT/SEC	UCOM	EATTM	SHPTM HP
75.4994	73.56	518.1	23.47	3.134	1.96	0.605	156.0	5021.0	0.097	0.310	431.6
75.5494	75.42	518.5	23.76	3.174	2.00	0.605	157.5	5046.6	0.097	0.310	446.4
75.5994	77.64	518.9	24.14	3.216	2.06	0.605	159.2	5072.5	0.097	0.310	464.6
75.6494	79.86	519.1	24.54	3.254	2.12	0.605	161.3	5095.8	0.097	0.311	484.0
75.6993	82.08	519.4	24.93	3.292	2.18	0.605	163.7	5118.2	0.098	0.313	504.6
75.7493	84.30	519.7	25.32	3.329	2.24	0.605	166.2	5139.9	0.098	0.315	526.2
75.7993	86.52	519.9	25.73	3.363	2.30	0.605	168.9	5159.7	0.099	0.318	548.5
75.8493	88.74	520.2	26.11	3.398	2.35	0.605	171.7	5179.7	0.100	0.320	571.8
75.8993	90.96	520.4	26.50	3.433	2.41	0.605	174.5	5199.0	0.101	0.323	595.6
75.9493	93.18	520.7	26.89	3.465	2.47	0.605	177.3	5217.0	0.102	0.326	619.9
75.9993	95.40	521.0	27.28	3.497	2.53	0.605	180.2	5234.6	0.103	0.329	644.8
76.0493	97.73	521.2	27.72	3.526	2.59	0.605	183.0	5250.2	0.104	0.333	670.7
76.0992	100.15	521.5	28.16	3.557	2.65	0.605	186.0	5266.8	0.105	0.336	698.0
76.1492	102.57	521.8	28.60	3.587	2.72	0.605	188.9	5282.9	0.107	0.339	726.0
76.1992	104.99	522.0	29.03	3.616	2.78	0.605	191.8	5298.4	0.108	0.342	754.6
76.2492	107.41	522.3	29.47	3.645	2.84	0.605	194.8	5313.4	0.109	0.345	783.7
76.2992	109.83	522.6	29.90	3.673	2.91	0.605	197.7	5327.9	0.110	0.349	813.2
76.3492	112.25	522.8	30.34	3.700	2.97	0.605	200.7	5342.0	0.111	0.352	843.3
76.3992	114.68	523.1	30.77	3.726	3.03	0.605	203.6	5355.4	0.112	0.355	873.7
76.4492	117.10	523.4	31.22	3.750	3.10	0.605	206.4	5367.7	0.114	0.359	904.4
76.4991	119.52	523.6	31.67	3.774	3.16	0.605	209.2	5379.7	0.115	0.362	935.4
76.5491	121.94	523.9	32.12	3.797	3.22	0.605	212.0	5391.1	0.116	0.365	966.8
76.5991	124.36	524.0	32.56	3.819	3.29	0.605	214.7	5402.0	0.117	0.368	998.6
76.6491	126.78	524.2	33.01	3.841	3.35	0.605	217.4	5412.6	0.118	0.372	1030.7
76.6991	129.20	524.4	33.45	3.862	3.41	0.605	220.1	5422.9	0.119	0.375	1063.1
76.7491	131.62	524.6	33.90	3.883	3.48	0.605	222.7	5432.8	0.120	0.378	1095.7
76.7991	134.05	524.8	34.34	3.904	3.54	0.605	225.2	5442.6	0.121	0.381	1128.2
76.8491	136.47	525.0	34.78	3.923	3.60	0.605	227.7	5452.0	0.122	0.384	1161.0
76.8990	138.89	525.1	35.22	3.943	3.67	0.605	230.1	5461.2	0.123	0.386	1194.0
76.9490	141.31	525.3	35.67	3.961	3.73	0.605	232.5	5469.9	0.125	0.389	1227.2
76.9990	143.73	525.5	36.15	3.976	3.79	0.605	234.8	5477.2	0.126	0.392	1260.3
77.0490	146.81	525.7	36.76	3.994	3.87	0.605	237.2	5485.6	0.127	0.395	1299.9
77.0990	149.94	525.9	37.37	4.012	3.96	0.605	239.6	5494.0	0.128	0.398	1341.1
77.1490	153.06	526.1	37.98	4.030	4.04	0.605	242.2	5502.2	0.129	0.401	1383.3
77.1990	156.18	526.2	38.59	4.047	4.12	0.605	244.8	5510.2	0.130	0.404	1426.4
77.2490	159.30	526.4	39.20	4.063	4.20	0.605	247.4	5518.1	0.131	0.407	1470.2
77.2990	162.42	526.6	39.81	4.080	4.28	0.605	250.0	5525.7	0.132	0.410	1514.7
77.3489	165.54	526.8	40.42	4.096	4.36	0.605	252.6	5533.1	0.133	0.413	1559.7
77.3989	168.67	527.0	41.02	4.112	4.45	0.605	255.3	5540.4	0.135	0.416	1605.3
77.4489	171.79	527.1	41.63	4.127	4.53	0.605	257.9	5547.5	0.136	0.420	1651.4
77.4989	174.91	527.3	42.23	4.142	4.61	0.605	260.4	5554.5	0.137	0.423	1698.0
77.5489	178.03	527.5	42.83	4.156	4.69	0.605	263.0	5561.3	0.138	0.426	1745.0
77.5989	181.15	527.7	43.43	4.171	4.77	0.605	265.5	5567.7	0.139	0.429	1792.4
77.6489	184.27	527.8	44.04	4.185	4.85	0.605	268.0	5574.0	0.140	0.432	1839.8
77.6989	187.40	528.0	44.64	4.198	4.93	0.605	270.2	5580.1	0.141	0.435	1886.5
77.7488	190.52	528.1	45.24	4.211	5.02	0.605	272.4	5586.0	0.143	0.437	1933.4
77.7988	193.64	528.3	45.84	4.224	5.10	0.605	274.6	5591.8	0.144	0.440	1980.4
77.8488	196.76	528.4	46.44	4.237	5.18	0.605	276.6	5597.5	0.145	0.442	2027.8
77.8988	199.88	528.6	47.04	4.249	5.26	0.605	278.9	5603.1	0.146	0.445	2075.4
77.9488	203.00	528.7	47.64	4.261	5.34	0.605	281.0	5608.5	0.147	0.447	2123.3

MAIN TURBINE

TIME SEC	TORQUE FT-LB
75.4994	222.0
75.5494	228.7
75.5994	236.6
75.6494	244.3
75.6993	252.0
75.7493	259.8
75.7993	267.4
75.8493	275.1
75.8993	282.6
75.9493	290.1
75.9993	297.7
76.0493	305.4
76.0992	313.5
76.1492	321.6
76.1992	329.8
76.2492	337.9
76.2992	346.0
76.3492	354.1
76.3992	362.1
76.4492	370.2
76.4991	378.2
76.5491	386.2
76.5991	394.3
76.6491	402.3
76.6991	410.3
76.7491	418.3
76.7991	426.2
76.8491	434.0
76.8990	441.9
76.9490	449.7
76.9990	457.4
77.0490	467.4
77.0990	477.4
77.1490	487.4
77.1990	497.4
77.2490	507.4
77.2990	517.4
77.3489	527.3
77.3989	537.3
77.4489	547.2
77.4989	557.2
77.5489	567.1
77.5989	577.1
77.6489	586.9
77.6989	596.3
77.7488	605.8
77.7988	615.3
77.8488	624.8
77.8988	634.2
77.9488	643.7

INDUCER AND SUCTION LINE

TIME SEC	PSLI PSIA	PII PSIA	TII DEG-R	SVI FT**3/LB	WSLI LB/SEC	QII GPM	WI LB/SEC	PTII PSIA	NI RPM	Q/NI GAL/REV	DPI PSI
77.9988	24.23	24.03	37.60	0.228	54.6	5597.86	54.59	24.3	6121.8	0.91	13.33
78.0488	24.14	23.93	37.60	0.228	55.0	5641.43	55.02	24.2	6185.7	0.91	13.66
78.0988	24.05	23.84	37.60	0.228	55.4	5683.70	55.43	24.1	6248.7	0.91	13.99
78.1487	23.97	23.76	37.60	0.228	55.8	5724.65	55.83	24.0	6311.0	0.91	14.32
78.1987	23.90	23.68	37.60	0.228	56.2	5764.70	56.22	23.9	6372.7	0.90	14.65
78.2487	23.82	23.60	37.60	0.228	56.6	5804.11	56.60	23.9	6433.4	0.90	14.99
78.2987	23.75	23.53	37.60	0.228	57.0	5842.98	56.98	23.8	6493.5	0.90	15.32
78.3487	23.68	23.45	37.60	0.228	57.4	5881.45	57.35	23.7	6552.7	0.90	15.64
78.3987	23.60	23.37	37.60	0.228	57.7	5919.52	57.73	23.6	6611.1	0.90	15.97
78.4487	23.53	23.30	37.60	0.228	58.1	5957.31	58.09	23.6	6668.4	0.89	16.28
78.4987	23.45	23.22	37.60	0.228	58.5	5994.76	58.46	23.5	6725.0	0.89	16.58
78.5486	23.38	23.14	37.60	0.228	58.8	6031.96	58.82	23.4	6780.3	0.89	16.87
78.5986	23.31	23.07	37.60	0.228	59.2	6068.86	59.18	23.4	6835.0	0.89	17.16
78.6486	23.23	22.99	37.60	0.228	59.5	6105.54	59.54	23.3	6888.6	0.89	17.45
78.6986	23.16	22.91	37.60	0.228	59.9	6141.92	59.89	23.2	6941.7	0.88	17.74
78.7486	23.08	22.83	37.60	0.228	60.2	6177.43	60.24	23.1	6993.9	0.88	18.03
78.7986	23.01	22.76	37.60	0.228	60.6	6212.17	60.57	23.1	7045.7	0.88	18.31
78.8486	22.94	22.68	37.60	0.228	60.9	6245.89	60.90	23.0	7098.0	0.88	18.61
78.8986	22.86	22.60	37.60	0.228	61.2	6279.87	61.23	22.9	7148.4	0.88	18.89
78.9485	22.79	22.53	37.60	0.228	61.6	6312.98	61.55	22.8	7199.4	0.88	19.19
78.9985	22.71	22.45	37.60	0.229	61.9	6346.37	61.88	22.8	7248.7	0.88	19.47
79.0485	22.64	22.37	37.60	0.229	62.2	6378.98	62.20	22.7	7298.7	0.87	19.76
79.0985	22.57	22.30	37.60	0.229	62.5	6405.90	62.46	22.6	7343.3	0.87	20.03
79.1485	22.49	22.22	37.60	0.229	62.7	6427.47	62.67	22.5	7384.2	0.87	20.29
79.1985	22.42	22.15	37.60	0.229	62.8	6446.13	62.85	22.5	7421.8	0.87	20.53
79.2485	22.35	22.07	37.60	0.229	63.0	6463.88	63.02	22.4	7455.0	0.87	20.74
79.2985	22.28	22.00	37.60	0.229	63.2	6480.39	63.18	22.3	7486.5	0.87	20.94
79.3484	22.20	21.93	37.60	0.229	63.3	6496.22	63.34	22.3	7516.4	0.86	21.13
79.3984	22.13	21.85	37.60	0.229	63.5	6512.28	63.49	22.2	7543.4	0.86	21.30
79.4484	22.06	21.78	37.60	0.229	63.6	6527.82	63.64	22.1	7570.0	0.86	21.46
79.4984	21.99	21.71	37.60	0.229	63.8	6543.07	63.79	22.0	7596.1	0.86	21.63
79.5484	21.92	21.63	37.60	0.229	63.9	6558.76	63.94	22.0	7619.9	0.86	21.77
79.5984	21.84	21.56	37.60	0.229	64.1	6574.04	64.09	21.9	7643.8	0.86	21.91
79.6484	21.77	21.49	37.60	0.229	64.2	6589.10	64.24	21.8	7667.8	0.86	22.06
79.6984	21.70	21.41	37.60	0.229	64.4	6604.61	64.39	21.8	7690.1	0.86	22.19
79.7484	21.63	21.34	37.60	0.229	64.5	6619.74	64.54	21.7	7712.6	0.86	22.33
79.7983	21.55	21.27	37.60	0.229	64.7	6634.68	64.68	21.6	7735.3	0.86	22.47
79.8483	21.48	21.19	37.60	0.229	64.8	6650.06	64.83	21.5	7756.7	0.86	22.59
79.8983	21.41	21.12	37.60	0.229	65.0	6665.07	64.98	21.5	7778.5	0.86	22.72
79.9483	21.34	21.05	37.60	0.229	65.1	6679.88	65.12	21.4	7800.6	0.86	22.86
79.9983	21.27	20.97	37.60	0.229	65.3	6694.57	65.26	21.3	7823.0	0.86	22.99
80.0483	21.24	20.95	37.60	0.229	65.4	6709.93	65.41	21.3	7843.4	0.86	23.12
80.0983	21.23	20.93	37.60	0.229	65.5	6723.27	65.54	21.3	7863.4	0.86	23.25
80.1483	21.21	20.91	37.60	0.229	65.7	6734.91	65.66	21.3	7882.6	0.85	23.37
80.1982	21.20	20.90	37.60	0.229	65.8	6745.64	65.76	21.3	7901.0	0.85	23.50
80.2482	21.18	20.88	37.60	0.229	65.9	6755.90	65.86	21.2	7918.8	0.85	23.62
80.2982	21.17	20.87	37.60	0.229	66.0	6766.59	65.96	21.2	7934.5	0.85	23.72
80.3482	21.15	20.85	37.60	0.229	66.1	6776.79	66.06	21.2	7950.1	0.85	23.82
80.3982	21.14	20.83	37.60	0.229	66.2	6786.74	66.16	21.2	7965.7	0.85	23.92
80.4482	21.12	20.82	37.60	0.229	66.3	6796.55	66.26	21.2	7981.3	0.85	24.03

INDUCER AND SUCTION LINE

TIME SEC	PTIE PSIA	PIE PSIA	DHI FT	DHI/N**2 FT/RPM**2	NPSPI PSI	NPSHI FT	NPSH/N**2 FT/RPM**2	EATPI	SHPI HP	TORQI FT-LB
77.9988	37.61	36.47	438.5	0.11702E-04	6.70	220.6	0.58851E-05	0.574	75.9	65.1
78.0488	37.84	36.68	449.3	0.11743E-04	6.61	217.5	0.56847E-05	0.574	78.3	66.5
78.0988	38.08	36.90	460.2	0.11785E-04	6.52	214.5	0.54927E-05	0.574	80.8	67.9
78.1487	38.34	37.14	471.1	0.11828E-04	6.44	212.0	0.53233E-05	0.574	83.2	69.3
78.1987	38.60	37.39	482.1	0.11871E-04	6.37	209.6	0.51612E-05	0.575	85.8	70.7
78.2487	38.86	37.63	493.0	0.11912E-04	6.30	207.2	0.50059E-05	0.575	88.3	72.1
78.2987	39.12	37.87	504.0	0.11953E-04	6.22	204.8	0.48563E-05	0.575	90.8	73.5
78.3487	39.37	38.11	514.7	0.11987E-04	6.15	202.4	0.47127E-05	0.575	93.4	74.9
78.3987	39.62	38.34	525.3	0.12019E-04	6.08	199.9	0.45745E-05	0.574	96.0	76.3
78.4487	39.85	38.56	535.6	0.12044E-04	6.00	197.5	0.44420E-05	0.574	98.6	77.7
78.4987	40.08	38.77	545.4	0.12060E-04	5.93	195.1	0.43141E-05	0.572	101.3	79.1
78.5486	40.30	38.98	555.1	0.12075E-04	5.86	192.7	0.41915E-05	0.571	103.9	80.5
78.5986	40.52	39.18	564.8	0.12089E-04	5.78	190.3	0.40730E-05	0.570	106.6	81.9
78.6486	40.74	39.38	574.2	0.12101E-04	5.71	187.9	0.39590E-05	0.569	109.2	83.3
78.6986	40.95	39.58	583.7	0.12113E-04	5.64	185.5	0.38485E-05	0.568	111.9	84.6
78.7486	41.16	39.77	593.1	0.12125E-04	5.56	183.0	0.37420E-05	0.567	114.5	86.0
78.7986	41.38	39.97	602.6	0.12138E-04	5.49	180.6	0.36385E-05	0.566	117.2	87.4
78.8486	41.60	40.18	612.4	0.12154E-04	5.42	178.2	0.35371E-05	0.565	120.0	88.8
78.8986	41.81	40.37	621.7	0.12167E-04	5.34	175.8	0.34403E-05	0.564	122.6	90.1
78.9485	42.03	40.58	631.4	0.12181E-04	5.27	173.4	0.33452E-05	0.563	125.4	91.5
78.9985	42.24	40.77	640.6	0.12193E-04	5.20	171.0	0.32541E-05	0.563	128.1	92.8
79.0485	42.46	40.98	650.3	0.12207E-04	5.12	168.6	0.31644E-05	0.562	130.9	94.2
79.0985	42.65	41.16	659.1	0.12223E-04	5.05	166.1	0.30810E-05	0.561	133.4	95.4
79.1485	42.84	41.33	667.6	0.12244E-04	4.98	163.7	0.30028E-05	0.560	135.8	96.6
79.1985	43.01	41.49	675.6	0.12265E-04	4.90	161.3	0.29291E-05	0.559	138.0	97.7
79.2485	43.14	41.62	682.5	0.12280E-04	4.83	159.0	0.28603E-05	0.559	140.0	98.6
79.2985	43.27	41.75	689.1	0.12295E-04	4.76	156.6	0.27941E-05	0.558	141.9	99.6
79.3484	43.39	41.86	695.4	0.12309E-04	4.69	154.2	0.27300E-05	0.557	143.7	100.4
79.3984	43.49	41.94	700.9	0.12317E-04	4.62	151.9	0.26689E-05	0.557	145.4	101.2
79.4484	43.58	42.03	706.3	0.12326E-04	4.54	149.5	0.26089E-05	0.556	147.0	102.0
79.4984	43.67	42.11	711.7	0.12334E-04	4.47	147.1	0.25501E-05	0.555	148.6	102.8
79.5484	43.74	42.18	716.4	0.12338E-04	4.40	144.8	0.24935E-05	0.555	150.1	103.5
79.5984	43.82	42.24	721.2	0.12343E-04	4.33	142.4	0.24375E-05	0.554	151.6	104.1
79.6484	43.89	42.31	726.0	0.12348E-04	4.26	140.1	0.23821E-05	0.554	153.1	104.9
79.6984	43.95	42.36	730.3	0.12350E-04	4.18	137.7	0.23284E-05	0.553	154.5	105.5
79.7484	44.01	42.42	734.8	0.12353E-04	4.11	135.3	0.22751E-05	0.553	155.9	106.2
79.7983	44.08	42.48	739.4	0.12357E-04	4.04	133.0	0.22222E-05	0.553	157.4	106.8
79.8483	44.13	42.53	743.5	0.12357E-04	3.97	130.6	0.21707E-05	0.552	158.7	107.5
79.8983	44.19	42.58	747.8	0.12359E-04	3.90	128.2	0.21195E-05	0.552	160.1	108.1
79.9483	44.25	42.63	752.2	0.12362E-04	3.82	125.9	0.20687E-05	0.551	161.6	108.8
79.9983	44.32	42.69	756.7	0.12365E-04	3.75	123.5	0.20183E-05	0.551	163.0	109.5
80.0483	44.42	42.79	760.8	0.12367E-04	3.73	122.8	0.19960E-05	0.551	164.4	110.1
80.0983	44.53	42.89	765.0	0.12373E-04	3.72	122.3	0.19776E-05	0.550	165.7	110.6
80.1483	44.65	43.00	769.2	0.12380E-04	3.70	121.8	0.19598E-05	0.550	166.9	111.2
80.1982	44.76	43.10	773.3	0.12388E-04	3.68	121.3	0.19427E-05	0.550	168.1	111.8
80.2482	44.86	43.20	777.3	0.12395E-04	3.67	120.8	0.19260E-05	0.550	169.3	112.3
80.2982	44.95	43.28	780.6	0.12399E-04	3.65	120.3	0.19106E-05	0.550	170.4	112.8
80.3482	45.03	43.36	783.9	0.12403E-04	3.64	119.8	0.18953E-05	0.549	171.4	113.2
80.3982	45.12	43.45	787.3	0.12408E-04	3.62	119.3	0.18801E-05	0.549	172.5	113.7
80.4482	45.21	43.53	790.7	0.12413E-04	3.61	118.8	0.18650E-05	0.549	173.5	114.2

MAIN PUMP

TIME SEC	PMI PSIA	PTMI PSIA	TMI DEG-R	SVM FT**3/LB	GMI GPM	WP LB/SEC	NM RPM	Q/NM GAL/REV	DPM PSI	PTME PSIA	PME PSIA
77.9968	36.47	37.61	37.60	0.228	5587.4	54.59	17460.6	0.320	385.32	422.93	418.09
78.0488	36.68	37.84	37.60	0.228	5630.6	55.02	17595.6	0.320	391.32	429.16	424.24
78.0988	36.90	38.08	37.60	0.228	5672.5	55.43	17726.6	0.320	397.18	435.26	430.27
78.1487	37.14	38.34	37.60	0.228	5713.1	55.83	17853.5	0.320	402.90	441.24	436.17
78.1987	37.39	38.60	37.60	0.228	5752.8	56.22	17977.5	0.320	408.53	447.13	442.00
78.2487	37.63	38.86	37.60	0.228	5791.8	56.60	18099.5	0.320	414.11	452.97	447.76
78.2987	37.87	39.12	37.60	0.228	5830.3	56.98	18219.8	0.320	419.65	458.77	453.49
78.3487	38.11	39.37	37.60	0.228	5868.4	57.35	18338.8	0.320	425.17	464.54	459.19
78.3987	38.34	39.62	37.60	0.228	5906.1	57.73	18456.6	0.320	430.67	470.28	464.87
78.4487	38.56	39.85	37.60	0.228	5943.5	58.09	18573.6	0.320	436.16	476.01	470.53
78.4987	38.77	40.08	37.60	0.228	5980.6	58.46	18689.4	0.320	441.63	481.71	476.16
78.5486	38.98	40.30	37.60	0.228	6017.5	58.82	18804.6	0.320	447.11	487.41	481.79
78.5986	39.18	40.52	37.60	0.228	6054.0	59.18	18918.8	0.320	452.57	493.09	487.40
78.6486	39.38	40.74	37.60	0.228	6090.3	59.54	19032.3	0.320	458.03	498.76	493.01
78.6986	39.58	40.95	37.60	0.228	6126.4	59.89	19144.9	0.320	463.48	504.43	498.60
78.7486	39.77	41.16	37.60	0.228	6161.5	60.24	19254.7	0.320	468.83	509.99	504.10
78.7986	39.97	41.38	37.60	0.228	6195.9	60.57	19362.2	0.320	474.09	515.47	509.51
78.8486	40.18	41.60	37.60	0.228	6229.3	60.90	19466.4	0.320	479.23	520.82	514.80
78.8986	40.37	41.81	37.60	0.228	6262.9	61.23	19571.5	0.320	484.43	526.24	520.15
78.9485	40.58	42.03	37.60	0.228	6295.6	61.55	19673.8	0.320	489.52	531.55	525.40
78.9985	40.77	42.24	37.60	0.228	6328.6	61.88	19777.0	0.320	494.69	536.93	530.71
79.0485	40.98	42.46	37.60	0.228	6360.9	62.20	19877.8	0.320	499.76	542.22	535.93
79.0985	41.16	42.65	37.60	0.228	6387.5	62.46	19960.8	0.320	503.96	546.61	540.27
79.1485	41.33	42.84	37.60	0.228	6408.7	62.67	20027.2	0.320	507.33	550.17	543.79
79.1985	41.49	43.01	37.60	0.228	6427.1	62.85	20084.6	0.320	510.26	553.26	546.85
79.2485	41.62	43.14	37.60	0.228	6444.5	63.02	20139.1	0.320	513.05	556.19	549.74
79.2985	41.75	43.27	37.60	0.228	6460.8	63.18	20190.0	0.320	515.65	558.92	552.44
79.3484	41.86	43.39	37.60	0.228	6476.4	63.34	20238.7	0.320	518.15	561.55	555.03
79.3984	41.94	43.49	37.60	0.228	6492.2	63.49	20288.2	0.320	520.70	564.19	557.64
79.4484	42.03	43.58	37.60	0.228	6507.6	63.64	20336.2	0.320	523.17	566.75	560.18
79.4984	42.11	43.67	37.60	0.228	6522.7	63.79	20383.3	0.320	525.61	569.28	562.67
79.5484	42.18	43.74	37.60	0.228	6538.1	63.94	20431.7	0.320	528.11	571.86	565.22
79.5984	42.24	43.82	37.60	0.228	6553.3	64.09	20478.9	0.320	530.56	574.38	567.71
79.6484	42.31	43.89	37.60	0.228	6568.2	64.24	20525.5	0.320	532.98	576.87	570.17
79.6984	42.36	43.95	37.60	0.228	6583.5	64.39	20573.4	0.320	535.48	579.43	572.70
79.7484	42.42	44.01	37.60	0.228	6598.5	64.54	20620.2	0.320	537.93	581.94	575.18
79.7983	42.48	44.08	37.60	0.228	6613.2	64.68	20666.4	0.320	540.34	584.42	577.63
79.8483	42.53	44.13	37.60	0.228	6628.5	64.83	20714.0	0.320	542.84	586.97	580.15
79.8983	42.58	44.19	37.60	0.228	6643.3	64.98	20760.4	0.320	545.28	589.47	582.62
79.9483	42.63	44.25	37.60	0.228	6658.0	65.12	20806.2	0.320	547.69	591.95	585.06
79.9983	42.69	44.32	37.60	0.228	6672.5	65.26	20851.6	0.320	550.09	594.41	587.49
80.0483	42.79	44.42	37.60	0.228	6687.7	65.41	20899.2	0.320	552.61	597.03	590.08
80.0983	42.89	44.53	37.60	0.228	6700.9	65.54	20940.4	0.320	554.80	599.33	592.36
80.1483	43.00	44.65	37.60	0.228	6712.4	65.66	20976.2	0.320	556.71	601.35	594.36
80.1982	43.10	44.76	37.60	0.228	6723.0	65.76	21009.3	0.320	558.47	603.23	596.21
80.2482	43.20	44.86	37.60	0.228	6733.1	65.86	21040.8	0.320	560.16	605.02	597.98
80.2982	43.28	44.95	37.60	0.228	6743.6	65.96	21073.7	0.320	561.92	606.87	599.81
80.3482	43.36	45.03	37.60	0.228	6753.7	66.06	21105.2	0.320	563.61	608.64	601.56
80.3982	43.45	45.12	37.60	0.228	6763.5	66.16	21135.9	0.320	565.26	610.38	603.27
80.4482	43.53	45.21	37.60	0.228	6773.2	66.26	21166.1	0.320	566.85	612.09	604.97

MAIN PUMP

TIME SEC	DHM FT	CFM/N**2 FT/RPM**2	NPSPM PSI	NPSHM FT	NPSH/N**2 FT/RPM**2	EATPM	SHPM HP	TORQM FT-LB
77.9988	12652.2	0.41500E-04	20.04	657.9	0.21578E-05	0.604	2079.3	625.4
78.0488	12848.7	0.41500E-04	20.27	665.6	0.21497E-05	0.604	2127.9	635.2
78.0988	13040.6	0.41500E-04	20.51	673.3	0.21427E-05	0.604	2175.9	644.7
78.1487	13228.0	0.41500E-04	20.76	681.8	0.21388E-05	0.604	2223.0	654.0
78.1987	13412.4	0.41500E-04	21.03	690.3	0.21358E-05	0.604	2269.8	663.1
78.2467	13595.1	0.41500E-04	21.28	698.7	0.21330E-05	0.604	2316.4	672.2
78.2967	13776.4	0.41500E-04	21.54	707.2	0.21305E-05	0.604	2363.0	681.2
78.3487	13957.0	0.41500E-04	21.79	715.4	0.21273E-05	0.604	2409.7	690.1
78.3987	14136.9	0.41500E-04	22.04	723.6	0.21242E-05	0.604	2456.5	699.0
78.4487	14316.5	0.41500E-04	22.28	731.4	0.21201E-05	0.604	2503.6	707.9
78.4987	14495.8	0.41500E-04	22.51	738.8	0.21151E-05	0.604	2550.8	716.8
78.5486	14674.9	0.41500E-04	22.73	746.0	0.21097E-05	0.604	2598.4	725.7
78.5986	14853.7	0.41500E-04	22.95	753.2	0.21043E-05	0.604	2646.1	734.6
78.6486	15032.4	0.41500E-04	23.16	760.2	0.20987E-05	0.604	2694.1	743.5
78.6986	15210.8	0.41500E-04	23.38	767.2	0.20932E-05	0.604	2742.3	752.3
78.7486	15385.9	0.41500E-04	23.59	774.1	0.20880E-05	0.604	2789.8	761.0
78.7986	15558.1	0.41500E-04	23.80	781.1	0.20836E-05	0.604	2836.9	769.5
78.8486	15726.1	0.41500E-04	24.03	788.5	0.20807E-05	0.604	2883.0	777.9
78.8986	15896.3	0.41500E-04	24.24	795.3	0.20764E-05	0.604	2930.1	786.3
78.9485	16062.9	0.41500E-04	24.46	802.5	0.20734E-05	0.604	2976.4	794.6
78.9985	16231.9	0.41500E-04	24.67	809.4	0.20693E-05	0.604	3023.5	803.0
79.0485	16397.7	0.41500E-04	24.88	816.5	0.20664E-05	0.604	3070.1	811.2
79.0985	16535.0	0.41500E-04	25.08	822.9	0.20653E-05	0.604	3108.8	818.0
79.1485	16645.2	0.41500E-04	25.26	828.9	0.20666E-05	0.604	3140.1	823.5
79.1985	16740.7	0.41500E-04	25.43	834.4	0.20686E-05	0.604	3167.2	828.2
79.2485	16831.8	0.41500E-04	25.57	839.0	0.20685E-05	0.604	3193.2	832.8
79.2985	16916.8	0.41500E-04	25.70	843.2	0.20684E-05	0.604	3217.5	837.0
79.3484	16998.7	0.41500E-04	25.82	847.0	0.20679E-05	0.604	3240.9	841.0
79.3984	17081.9	0.41500E-04	25.91	850.1	0.20654E-05	0.604	3264.8	845.2
79.4484	17162.8	0.41500E-04	26.01	853.2	0.20630E-05	0.604	3288.1	849.2
79.4984	17242.3	0.41500E-04	26.10	856.2	0.20606E-05	0.604	3311.0	853.1
79.5484	17324.4	0.41500E-04	26.17	858.5	0.20565E-05	0.604	3334.7	857.2
79.5984	17404.6	0.41500E-04	26.24	860.9	0.20527E-05	0.604	3357.9	861.2
79.6484	17483.8	0.41500E-04	26.32	863.3	0.20492E-05	0.604	3380.9	865.1
79.6984	17565.5	0.41500E-04	26.38	865.3	0.20443E-05	0.604	3404.7	869.2
79.7484	17645.5	0.41500E-04	26.44	867.3	0.20399E-05	0.604	3428.0	873.1
79.7983	17724.6	0.41500E-04	26.51	869.5	0.20358E-05	0.604	3451.1	877.1
79.8483	17806.3	0.41500E-04	26.56	871.3	0.20306E-05	0.604	3475.0	881.1
79.8983	17886.3	0.41500E-04	26.62	873.2	0.20260E-05	0.604	3498.5	885.1
79.9483	17965.2	0.41500E-04	26.68	875.2	0.20218E-05	0.604	3521.7	889.0
79.9983	18043.8	0.41500E-04	26.75	877.4	0.20179E-05	0.604	3544.8	892.9
80.0483	18126.2	0.41500E-04	26.85	880.7	0.20164E-05	0.604	3569.2	897.0
80.0983	18197.7	0.41500E-04	26.96	884.4	0.20168E-05	0.604	3590.4	900.5
80.1483	18260.1	0.41500E-04	27.07	888.0	0.20182E-05	0.604	3608.9	903.6
80.1982	18317.6	0.41500E-04	27.18	891.6	0.20199E-05	0.604	3626.1	906.5
80.2482	18372.7	0.41500E-04	27.29	895.0	0.20217E-05	0.604	3642.5	909.2
80.2982	18430.2	0.41500E-04	27.37	897.8	0.20216E-05	0.604	3659.7	912.1
80.3482	18485.3	0.41500E-04	27.46	900.6	0.20220E-05	0.604	3676.1	914.8
80.3982	18539.1	0.41500E-04	27.55	903.5	0.20225E-05	0.604	3692.2	917.5
80.4482	18592.2	0.41500E-04	27.64	906.4	0.20232E-05	0.604	3708.2	920.1

INDUCER TURBINE

TIME SEC	PTTI1 PSIA	TTI1 DEG-R	PTE1 PSIA	PR1	WT LB/SEC	FP1	DHT1 BTU/LB	CC1 FT/SEC	UC01	EATT1	SHPT1 HP
77.9988	48.24	450.2	25.52	1.890	5.42	2.383	11.3	3624.4	0.078	0.043	86.4
78.0488	48.82	449.7	25.73	1.897	5.50	2.388	11.4	3632.7	0.076	0.043	88.8
78.0988	49.43	449.4	25.94	1.905	5.58	2.392	11.6	3641.8	0.079	0.044	91.3
78.1487	50.04	449.0	26.14	1.914	5.65	2.394	11.7	3652.2	0.079	0.044	93.8
78.1987	50.64	448.6	26.36	1.921	5.73	2.396	11.9	3660.5	0.080	0.044	96.2
78.2487	51.25	448.3	26.56	1.929	5.81	2.399	12.0	3670.3	0.080	0.045	98.7
78.2987	51.85	448.0	26.78	1.936	5.88	2.401	12.2	3678.2	0.081	0.045	101.2
78.3487	52.46	447.6	26.98	1.944	5.96	2.403	12.3	3687.4	0.082	0.045	103.7
78.3987	53.06	447.3	27.20	1.951	6.03	2.405	12.4	3694.8	0.082	0.046	106.2
78.4487	53.67	447.0	27.40	1.959	6.11	2.408	12.6	3703.5	0.083	0.046	108.8
78.4987	54.27	446.6	27.62	1.965	6.19	2.410	12.7	3710.4	0.083	0.046	111.3
78.5486	54.88	446.3	27.82	1.973	6.26	2.412	12.9	3718.5	0.084	0.047	113.9
78.5986	55.47	445.9	28.04	1.978	6.34	2.414	13.0	3724.5	0.084	0.047	116.5
78.6486	56.08	445.5	28.24	1.986	6.42	2.416	13.1	3732.3	0.085	0.047	119.1
78.6986	56.68	445.2	28.46	1.992	6.49	2.417	13.2	3738.1	0.085	0.047	121.6
78.7486	57.29	444.9	28.67	1.999	6.57	2.420	13.4	3745.7	0.086	0.048	124.3
78.7986	57.96	444.6	28.88	2.007	6.66	2.421	13.5	3754.6	0.086	0.048	127.2
78.8486	58.52	444.3	29.09	2.012	6.72	2.422	13.6	3759.2	0.087	0.048	129.6
78.8986	59.19	444.0	29.31	2.019	6.81	2.424	13.8	3767.7	0.087	0.049	132.5
78.9485	59.75	443.7	29.52	2.024	6.88	2.425	13.9	3772.5	0.088	0.049	135.0
78.9985	60.42	443.4	29.74	2.032	6.96	2.426	14.0	3780.5	0.088	0.049	137.9
79.0485	60.72	443.1	29.85	2.034	7.00	2.427	14.1	3782.0	0.089	0.049	139.7
79.0985	61.05	442.9	29.96	2.038	7.04	2.428	14.2	3785.5	0.089	0.050	141.5
79.1485	61.37	442.8	30.06	2.041	7.08	2.428	14.3	3789.2	0.089	0.050	143.3
79.1985	61.61	442.6	30.16	2.043	7.11	2.429	14.4	3790.3	0.090	0.050	144.7
79.2485	61.93	442.5	30.26	2.046	7.15	2.429	14.5	3794.0	0.090	0.050	146.4
79.2985	62.25	442.4	30.37	2.050	7.19	2.430	14.5	3797.8	0.090	0.050	148.0
79.3484	62.50	442.3	30.48	2.051	7.22	2.430	14.6	3798.3	0.091	0.051	149.2
79.3984	62.82	442.2	30.57	2.055	7.26	2.431	14.7	3802.9	0.091	0.051	150.8
79.4484	63.15	442.1	30.68	2.058	7.30	2.432	14.7	3806.6	0.091	0.051	152.3
79.4984	63.39	442.0	30.78	2.059	7.33	2.432	14.8	3807.0	0.092	0.051	153.5
79.5484	63.72	441.9	30.89	2.063	7.37	2.433	14.9	3810.6	0.092	0.051	155.0
79.5984	64.04	441.8	30.99	2.067	7.41	2.433	14.9	3815.0	0.092	0.051	156.5
79.6484	64.28	441.7	31.09	2.068	7.44	2.434	15.0	3815.4	0.092	0.052	157.7
79.6984	64.61	441.6	31.20	2.071	7.48	2.434	15.0	3818.9	0.092	0.052	159.2
79.7484	64.93	441.5	31.31	2.074	7.52	2.435	15.1	3822.3	0.093	0.052	160.6
79.7983	65.18	441.4	31.40	2.076	7.55	2.435	15.1	3823.5	0.093	0.052	161.8
79.8483	65.50	441.3	31.51	2.079	7.59	2.436	15.2	3826.9	0.093	0.052	163.3
79.8983	65.82	441.2	31.61	2.082	7.63	2.436	15.3	3830.2	0.093	0.052	164.8
79.9483	66.15	441.1	31.72	2.085	7.68	2.437	15.3	3833.5	0.093	0.052	166.3
79.9983	66.36	441.0	31.82	2.086	7.70	2.437	15.4	3833.7	0.094	0.052	167.4
80.0483	66.61	440.9	31.90	2.088	7.73	2.438	15.4	3836.0	0.094	0.052	168.6
80.0983	66.83	440.8	31.97	2.090	7.76	2.438	15.5	3838.0	0.094	0.053	169.7
80.1483	67.05	440.7	32.04	2.092	7.79	2.438	15.5	3840.0	0.094	0.053	170.8
80.1982	67.26	440.6	32.11	2.094	7.81	2.439	15.6	3842.1	0.094	0.053	171.9
80.2482	67.39	440.5	32.17	2.095	7.83	2.439	15.6	3841.7	0.095	0.053	172.7
80.2982	67.61	440.5	32.25	2.097	7.86	2.439	15.6	3843.7	0.095	0.053	173.7
80.3482	67.82	440.4	32.32	2.099	7.88	2.440	15.7	3845.8	0.095	0.053	174.8
80.3982	68.04	440.3	32.39	2.101	7.91	2.440	15.7	3847.8	0.095	0.053	175.8
80.4482	68.26	440.3	32.46	2.103	7.94	2.440	15.7	3849.8	0.095	0.053	176.8

INDUCER TURBINE

TIME SEC	TORQIT FT-LB
77.9988	74.1
78.0488	75.4
78.0988	76.7
78.1487	78.0
78.1987	79.3
78.2487	80.6
78.2987	81.8
78.3487	83.1
78.3987	84.4
78.4487	85.7
78.4987	86.9
78.5486	88.2
78.5986	89.5
78.6486	90.8
78.6986	92.0
78.7486	93.3
78.7986	94.8
78.8486	95.9
78.8986	97.3
78.9485	98.5
78.9985	99.9
79.0485	100.5
79.0985	101.2
79.1485	101.9
79.1985	102.4
79.2485	103.1
79.2985	103.8
79.3484	104.3
79.3984	105.0
79.4484	105.7
79.4984	106.1
79.5484	106.8
79.5984	107.6
79.6484	108.0
79.6984	108.7
79.7484	109.4
79.7983	109.9
79.8483	110.6
79.8983	111.3
79.9483	112.0
79.9983	112.4
80.0483	112.9
80.0983	113.4
80.1483	113.8
80.1982	114.3
80.2482	114.5
80.2982	115.0
80.3482	115.5
80.3982	115.9
80.4482	116.4

MAIN TURBINE

TIME SEC	PTTIM PSIA	TTIM DEG-R	PTTEM PSIA	PRM	WT LB/SEC	EPM	DHTM BTU/LB	CCM FT/SEC	UCOM	EATTM	SHPTM HP
77.9968	206.13	528.8	48.24	4.273	5.42	0.605	283.0	5613.9	0.148	0.450	2171.5
78.0488	209.09	529.0	48.82	4.283	5.50	0.605	285.0	5618.6	0.149	0.452	2218.1
78.0988	212.03	529.1	49.43	4.290	5.58	0.605	286.9	5622.0	0.150	0.455	2263.9
78.1487	214.97	529.3	50.04	4.296	5.65	0.605	288.8	5625.4	0.151	0.457	2309.7
78.1987	217.92	529.4	50.64	4.303	5.73	0.605	290.6	5628.9	0.152	0.459	2355.6
78.2487	220.86	529.6	51.25	4.309	5.81	0.605	292.3	5632.1	0.153	0.461	2401.6
78.2987	223.80	529.7	51.85	4.316	5.88	0.605	294.1	5635.5	0.154	0.464	2447.8
78.3487	226.74	529.9	52.46	4.322	5.96	0.605	295.8	5638.7	0.155	0.466	2494.2
78.3987	229.68	530.0	53.06	4.329	6.04	0.605	297.5	5642.0	0.155	0.468	2541.0
78.4487	232.62	530.2	53.67	4.334	6.11	0.605	299.2	5645.0	0.156	0.470	2587.8
78.4987	235.57	530.3	54.27	4.341	6.19	0.605	300.9	5648.3	0.157	0.472	2635.0
78.5486	238.51	530.4	54.88	4.346	6.27	0.605	302.6	5651.1	0.158	0.474	2682.4
78.5986	241.45	530.5	55.47	4.352	6.34	0.605	304.3	5653.9	0.159	0.477	2730.1
78.6486	244.39	530.6	56.08	4.358	6.42	0.605	305.9	5656.4	0.160	0.479	2777.9
78.6986	247.33	530.6	56.68	4.364	6.50	0.605	307.3	5659.0	0.161	0.481	2824.6
78.7486	250.27	530.7	57.29	4.369	6.57	0.605	308.7	5661.4	0.162	0.482	2870.8
78.7986	253.22	530.8	57.96	4.369	6.65	0.605	309.9	5661.9	0.162	0.484	2915.9
78.8486	256.16	530.8	58.52	4.378	6.73	0.605	311.4	5665.7	0.163	0.486	2963.1
78.8986	259.10	530.9	59.19	4.378	6.80	0.605	312.6	5666.3	0.164	0.487	3008.5
78.9485	262.04	531.0	59.75	4.386	6.88	0.605	313.9	5669.7	0.165	0.489	3055.8
78.9985	264.98	531.0	60.42	4.386	6.96	0.605	315.1	5670.3	0.166	0.491	3101.5
79.0485	266.71	531.1	60.72	4.392	7.00	0.605	316.4	5673.2	0.166	0.492	3134.7
79.0985	268.14	531.2	61.05	4.392	7.04	0.605	317.4	5673.6	0.167	0.494	3160.7
79.1485	269.57	531.3	61.37	4.392	7.08	0.605	318.1	5674.1	0.168	0.495	3185.0
79.1985	271.00	531.3	61.61	4.399	7.11	0.605	319.0	5676.9	0.168	0.496	3210.1
79.2485	272.42	531.4	61.93	4.399	7.15	0.605	319.6	5677.3	0.169	0.497	3233.2
79.2985	273.85	531.5	62.25	4.399	7.19	0.605	320.2	5677.8	0.169	0.497	3256.0
79.3484	275.28	531.5	62.50	4.405	7.22	0.605	320.9	5680.2	0.169	0.498	3280.1
79.3984	276.71	531.6	62.82	4.405	7.26	0.605	321.5	5680.7	0.170	0.499	3302.9
79.4484	278.14	531.7	63.15	4.405	7.30	0.605	322.1	5681.1	0.170	0.500	3325.5
79.4984	279.56	531.7	63.39	4.410	7.33	0.605	322.8	5683.5	0.170	0.500	3349.6
79.5484	280.99	531.8	63.72	4.410	7.37	0.605	323.3	5684.0	0.171	0.501	3372.5
79.5984	282.42	531.9	64.04	4.410	7.41	0.605	323.9	5684.4	0.171	0.502	3395.2
79.6484	283.85	531.9	64.28	4.415	7.45	0.605	324.6	5686.8	0.172	0.503	3419.4
79.6984	285.27	532.0	64.61	4.415	7.48	0.605	325.2	5687.2	0.172	0.503	3442.4
79.7484	286.70	532.1	64.93	4.415	7.52	0.605	325.7	5687.7	0.172	0.504	3465.2
79.7983	288.13	532.1	65.18	4.421	7.56	0.605	326.4	5690.0	0.173	0.505	3489.6
79.8483	289.56	532.2	65.50	4.421	7.59	0.605	326.9	5690.4	0.173	0.506	3512.7
79.8983	290.99	532.3	65.82	4.421	7.63	0.605	327.5	5690.9	0.173	0.506	3535.7
79.9483	292.41	532.3	66.15	4.421	7.67	0.605	328.0	5691.3	0.174	0.507	3558.7
79.9983	293.84	532.4	66.36	4.428	7.70	0.605	328.8	5694.3	0.174	0.508	3583.7
80.0483	294.93	532.5	66.61	4.428	7.73	0.605	329.3	5694.6	0.174	0.508	3602.9
80.0983	295.90	532.5	66.83	4.428	7.76	0.605	329.8	5694.9	0.175	0.509	3619.8
80.1483	296.86	532.5	67.05	4.428	7.78	0.605	330.2	5695.1	0.175	0.510	3636.1
80.1982	297.83	532.6	67.26	4.428	7.81	0.605	330.6	5695.4	0.175	0.510	3652.0
80.2482	298.80	532.6	67.39	4.434	7.83	0.605	331.1	5697.8	0.175	0.511	3669.6
80.2982	299.76	532.6	67.61	4.434	7.86	0.605	331.5	5698.1	0.176	0.511	3685.6
80.3482	300.73	532.7	67.82	4.434	7.88	0.605	331.9	5698.4	0.176	0.512	3701.5
80.3982	301.69	532.7	68.04	4.434	7.91	0.605	332.2	5698.6	0.176	0.512	3717.3
80.4482	302.66	532.8	68.26	4.434	7.93	0.605	332.6	5698.9	0.176	0.513	3733.0

APPENDIX B

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MAIN TURBINE

TIME SEC	TORQUE FT-LB
77.9988	653.2
78.0488	662.1
78.0988	670.8
78.1487	679.5
78.1987	688.2
78.2487	696.9
78.2987	705.6
78.3487	714.3
78.3987	723.1
78.4487	731.8
78.4987	740.5
78.5486	749.2
78.5986	757.9
78.6486	766.6
78.6986	774.9
78.7486	783.1
78.7986	790.9
78.8486	799.4
78.8986	807.3
78.9485	815.8
78.9985	823.7
79.0485	828.2
79.0985	831.7
79.1485	835.3
79.1985	839.4
79.2485	843.2
79.2985	847.0
79.3484	851.2
79.3984	855.0
79.4484	858.9
79.4984	863.1
79.5484	866.9
79.5984	870.8
79.6484	875.0
79.6984	878.8
79.7484	882.6
79.7983	886.8
79.8483	890.7
79.8983	894.5
79.9483	898.3
79.9983	902.7
80.0483	905.4
80.0983	907.9
80.1483	910.4
80.1982	913.0
80.2482	916.0
80.2982	918.6
80.3482	921.1
80.3982	923.7
80.4482	926.3

INDUCER AND SUCTION LINE

TIME SEC	PSLI PSIA	PII PSIA	TII DEG-R	SVI FT**3/LB	WSLI LB/SEC	QII GPM	WI LB/SEC	PTII PSIA	NI RPM	Q/NI GAL/REV	DPI PSI
80.4982	21.11	20.80	37.60	0.229	66.4	6806.29	66.35	21.2	7996.7	0.85	24.13
80.5482	21.09	20.79	37.60	0.229	66.4	6815.98	66.45	21.2	8012.0	0.85	24.23
80.5981	21.08	20.77	37.60	0.229	66.5	6825.64	66.54	21.1	8027.3	0.85	24.33
80.6481	21.06	20.75	37.60	0.229	66.6	6834.83	66.63	21.1	8042.2	0.85	24.43
80.6981	21.05	20.74	37.60	0.229	66.7	6843.13	66.71	21.1	8056.3	0.85	24.53
80.7481	21.03	20.72	37.60	0.229	66.8	6851.61	66.79	21.1	8068.1	0.85	24.60
80.7981	21.02	20.71	37.60	0.229	66.9	6859.51	66.87	21.1	8079.9	0.85	24.68
80.8481	21.00	20.69	37.60	0.229	66.9	6867.12	66.94	21.1	8091.5	0.85	24.76
80.8981	20.99	20.68	37.60	0.229	67.0	6874.58	67.02	21.0	8103.0	0.85	24.83
80.9481	20.97	20.66	37.60	0.229	67.1	6881.95	67.09	21.0	8114.4	0.85	24.91
80.9980	20.96	20.64	37.60	0.229	67.2	6889.28	67.16	21.0	8126.0	0.85	24.99
81.0480	20.94	20.63	37.60	0.229	67.2	6896.58	67.23	21.0	8137.4	0.85	25.07
81.0980	20.93	20.61	37.60	0.229	67.3	6903.86	67.30	21.0	8148.8	0.85	25.14
81.1480	20.91	20.60	37.60	0.229	67.4	6910.95	67.37	21.0	8160.0	0.85	25.22
81.1980	20.90	20.58	37.60	0.229	67.4	6916.35	67.42	21.0	8169.9	0.85	25.29
81.2480	20.88	20.57	37.60	0.229	67.5	6920.88	67.47	20.9	8178.9	0.85	25.35
81.2980	20.87	20.55	37.60	0.229	67.5	6924.96	67.51	20.9	8187.1	0.85	25.41
81.3480	20.85	20.54	37.60	0.229	67.5	6928.82	67.54	20.9	8194.7	0.85	25.47
81.3979	20.84	20.52	37.60	0.229	67.6	6932.56	67.58	20.9	8201.8	0.85	25.52
81.4479	20.82	20.51	37.60	0.229	67.6	6936.24	67.62	20.9	8208.5	0.85	25.56
81.4979	20.81	20.49	37.60	0.229	67.7	6939.89	67.65	20.9	8214.9	0.84	25.61
81.5479	20.80	20.48	37.60	0.229	67.7	6943.52	67.69	20.9	8221.1	0.84	25.65
81.5979	20.78	20.46	37.60	0.229	67.7	6947.13	67.72	20.8	8227.1	0.84	25.69
81.6479	20.77	20.45	37.60	0.229	67.8	6950.72	67.76	20.8	8233.0	0.84	25.73
81.6979	20.75	20.43	37.60	0.229	67.8	6954.31	67.79	20.8	8238.8	0.84	25.77
81.7479	20.74	20.42	37.60	0.229	67.8	6958.55	67.83	20.8	8242.8	0.84	25.79
81.7979	20.72	20.40	37.60	0.229	67.9	6962.44	67.87	20.8	8247.1	0.84	25.82
81.8478	20.71	20.39	37.60	0.229	67.9	6966.16	67.91	20.8	8251.7	0.84	25.84
81.8978	20.69	20.37	37.60	0.229	67.9	6969.81	67.94	20.8	8256.5	0.84	25.87
81.9478	20.68	20.36	37.60	0.229	68.0	6973.41	67.98	20.7	8261.5	0.84	25.90
81.9978	20.67	20.34	37.60	0.229	68.0	6976.99	68.01	20.7	8266.5	0.84	25.94
82.0478	20.64	20.32	37.60	0.229	68.0	6980.57	68.05	20.7	8271.8	0.84	25.97
82.0978	20.60	20.28	37.60	0.229	68.1	6984.52	68.09	20.7	8277.4	0.84	26.00
82.1478	20.57	20.25	37.60	0.229	68.1	6988.96	68.13	20.6	8283.3	0.84	26.04
82.1978	20.54	20.21	37.60	0.229	68.2	6993.64	68.17	20.6	8289.6	0.84	26.08
82.2477	20.50	20.18	37.60	0.229	68.2	6998.45	68.22	20.6	8296.1	0.84	26.12
82.2977	20.47	20.14	37.60	0.229	68.3	7003.30	68.27	20.5	8302.8	0.84	26.16
82.3477	20.43	20.11	37.60	0.229	68.3	7008.19	68.31	20.5	8309.6	0.84	26.20
82.3977	20.40	20.08	37.60	0.229	68.4	7013.09	68.36	20.5	8316.6	0.84	26.24
82.4477	20.37	20.04	37.60	0.229	68.4	7017.99	68.41	20.4	8323.6	0.84	26.29
82.4977	20.33	20.01	37.60	0.229	68.5	7022.90	68.46	20.4	8330.7	0.84	26.33
82.5477	20.30	19.97	37.60	0.229	68.5	7027.79	68.50	20.4	8337.9	0.84	26.38
82.5977	20.26	19.94	37.60	0.229	68.6	7032.70	68.55	20.3	8345.0	0.84	26.42
82.6476	20.23	19.90	37.60	0.229	68.6	7037.59	68.60	20.3	8352.2	0.84	26.47
82.6976	20.20	19.87	37.60	0.229	68.6	7042.48	68.65	20.3	8359.5	0.84	26.52
82.7476	20.16	19.84	37.60	0.229	68.7	7047.37	68.69	20.2	8366.7	0.84	26.56
82.7976	20.13	19.80	37.60	0.229	68.7	7052.27	68.74	20.2	8373.9	0.84	26.61
82.8476	20.09	19.77	37.60	0.229	68.8	7057.15	68.79	20.2	8381.2	0.84	26.66
82.8976	20.06	19.73	37.60	0.229	68.8	7062.04	68.84	20.1	8388.4	0.84	26.70
82.9476	20.03	19.70	37.60	0.229	68.9	7066.91	68.88	20.1	8395.7	0.84	26.75

INDUCER AND SUCTION LINE

TIME SEC	PTIE PSIA	PIE PSIA	DHI FT	DHI/N**2 FT/RPM**2	NPSPI PSI	NPSHI FT	NPSH/N**2 FT/RPM**2	EATPI	SHPI HP	TORQI FT-LB
80.4982	45.30	43.61	794.1	0.12418E-04	3.59	118.3	0.18501E-05	0.549	174.5	114.6
80.5482	45.38	43.69	797.4	0.12423E-04	3.58	117.8	0.18354E-05	0.549	175.6	115.1
80.5981	45.47	43.78	800.8	0.12428E-04	3.57	117.3	0.18208E-05	0.548	176.6	115.6
80.6481	45.56	43.86	804.1	0.12433E-04	3.55	116.8	0.18064E-05	0.548	177.7	116.0
80.6981	45.64	43.93	807.3	0.12438E-04	3.54	116.3	0.17925E-05	0.548	178.6	116.5
80.7481	45.70	43.99	809.8	0.12440E-04	3.52	115.9	0.17798E-05	0.548	179.4	116.8
80.7981	45.76	44.05	812.3	0.12442E-04	3.51	115.4	0.17671E-05	0.548	180.2	117.2
80.8481	45.82	44.11	814.8	0.12445E-04	3.49	114.9	0.17546E-05	0.548	181.1	117.5
80.8981	45.88	44.16	817.3	0.12448E-04	3.48	114.4	0.17422E-05	0.548	181.9	117.9
80.9481	45.94	44.22	819.8	0.12451E-04	3.46	113.9	0.17299E-05	0.547	182.7	118.2
80.9980	46.01	44.28	822.4	0.12455E-04	3.45	113.4	0.17177E-05	0.547	183.5	118.6
81.0480	46.07	44.34	824.9	0.12458E-04	3.43	112.9	0.17055E-05	0.547	184.3	118.9
81.0980	46.13	44.40	827.4	0.12461E-04	3.42	112.5	0.16935E-05	0.547	185.1	119.3
81.1480	46.19	44.46	829.9	0.12464E-04	3.40	112.0	0.16815E-05	0.547	185.9	119.6
81.1980	46.25	44.51	832.3	0.12469E-04	3.39	111.5	0.16701E-05	0.547	186.6	119.9
81.2480	46.30	44.56	834.4	0.12473E-04	3.37	111.0	0.16592E-05	0.547	187.2	120.2
81.2980	46.34	44.60	836.3	0.12477E-04	3.36	110.5	0.16488E-05	0.547	187.8	120.5
81.3480	46.38	44.64	838.1	0.12481E-04	3.34	110.0	0.16386E-05	0.546	188.4	120.7
81.3979	46.42	44.67	839.8	0.12484E-04	3.33	109.6	0.16287E-05	0.546	188.9	121.0
81.4479	46.45	44.70	841.4	0.12487E-04	3.31	109.1	0.16190E-05	0.546	189.4	121.2
81.4979	46.48	44.73	842.8	0.12489E-04	3.30	108.6	0.16095E-05	0.546	189.8	121.4
81.5479	46.51	44.76	844.2	0.12491E-04	3.29	108.1	0.16000E-05	0.546	190.3	121.6
81.5979	46.54	44.78	845.6	0.12493E-04	3.27	107.7	0.15907E-05	0.546	190.7	121.8
81.6479	46.56	44.81	846.9	0.12494E-04	3.26	107.2	0.15814E-05	0.546	191.2	121.9
81.6979	46.59	44.83	848.2	0.12496E-04	3.24	106.7	0.15722E-05	0.546	191.6	122.1
81.7479	46.59	44.83	848.8	0.12493E-04	3.23	106.2	0.15638E-05	0.546	191.9	122.2
81.7979	46.60	44.84	849.7	0.12492E-04	3.21	105.8	0.15551E-05	0.546	192.2	122.4
81.8478	46.62	44.85	850.6	0.12492E-04	3.20	105.3	0.15464E-05	0.546	192.5	122.5
81.8978	46.63	44.87	851.5	0.12491E-04	3.18	104.8	0.15377E-05	0.545	192.8	122.7
81.9478	46.65	44.88	852.6	0.12492E-04	3.17	104.3	0.15289E-05	0.545	193.2	122.8
81.9978	46.67	44.90	853.6	0.12492E-04	3.16	103.9	0.15201E-05	0.545	193.6	123.0
82.0478	46.67	44.90	854.7	0.12492E-04	3.13	102.9	0.15044E-05	0.545	194.0	123.2
82.0978	46.67	44.90	855.9	0.12492E-04	3.09	101.8	0.14863E-05	0.545	194.4	123.3
82.1478	46.67	44.90	857.0	0.12491E-04	3.06	100.7	0.14680E-05	0.545	194.8	123.5
82.1978	46.68	44.90	858.3	0.12490E-04	3.03	99.6	0.14496E-05	0.545	195.3	123.7
82.2477	46.68	44.90	859.6	0.12489E-04	2.99	98.5	0.14312E-05	0.545	195.8	123.9
82.2977	46.69	44.91	860.9	0.12489E-04	2.96	97.4	0.14128E-05	0.544	196.3	124.2
82.3477	46.70	44.91	862.3	0.12489E-04	2.93	96.3	0.13943E-05	0.544	196.8	124.4
82.3977	46.71	44.92	863.8	0.12489E-04	2.89	95.2	0.13759E-05	0.544	197.3	124.6
82.4477	46.72	44.93	865.2	0.12489E-04	2.86	94.1	0.13575E-05	0.544	197.8	124.8
82.4977	46.73	44.94	866.7	0.12489E-04	2.82	92.9	0.13392E-05	0.544	198.4	125.1
82.5477	46.74	44.95	868.2	0.12489E-04	2.79	91.8	0.13209E-05	0.544	198.9	125.3
82.5977	46.75	44.96	869.7	0.12489E-04	2.76	90.7	0.13026E-05	0.544	199.4	125.5
82.6476	46.77	44.97	871.3	0.12489E-04	2.72	89.6	0.12845E-05	0.543	200.0	125.7
82.6976	46.78	44.98	872.8	0.12490E-04	2.69	88.5	0.12663E-05	0.543	200.5	126.0
82.7476	46.79	44.99	874.3	0.12490E-04	2.65	87.4	0.12482E-05	0.543	201.1	126.2
82.7976	46.80	45.00	875.9	0.12490E-04	2.62	86.3	0.12302E-05	0.543	201.6	126.5
82.8476	46.82	45.01	877.4	0.12491E-04	2.59	85.2	0.12122E-05	0.543	202.2	126.7
82.8976	46.83	45.02	879.0	0.12491E-04	2.55	84.0	0.11943E-05	0.543	202.7	126.9
82.9476	46.84	45.03	880.5	0.12492E-04	2.52	82.9	0.11765E-05	0.543	203.3	127.2

MAIN PUMP

TIME SEC	FMI PSIA	FTMI PSIA	TMI DEG-R	SVM FT**3/LB	GMI GPM	WP LB/SEC	NM RPM	Q/NM GAL/REV	DPM PSI	PTME PSIA	PME PSIA
80.4982	43.61	45.30	37.60	0.228	6782.8	66.35	21196.1	0.320	568.50	613.80	606.65
80.5482	43.69	45.38	37.60	0.228	6792.3	66.45	21226.0	0.320	570.11	615.49	608.33
80.5981	43.78	45.47	37.60	0.228	6801.8	66.54	21255.7	0.320	571.72	617.19	610.00
80.6481	43.86	45.56	37.60	0.228	6810.9	66.63	21284.0	0.320	573.25	618.80	611.60
80.6981	43.93	45.64	37.60	0.228	6819.1	66.71	21309.6	0.320	574.63	620.27	613.05
80.7481	43.99	45.70	37.60	0.228	6827.4	66.79	21335.7	0.320	576.05	621.75	614.50
80.7981	44.05	45.76	37.60	0.228	6835.2	66.87	21360.0	0.320	577.37	623.13	615.87
80.8481	44.11	45.82	37.60	0.228	6842.7	66.94	21383.5	0.320	578.65	624.47	617.19
80.8981	44.16	45.88	37.60	0.228	6850.1	67.02	21406.5	0.320	579.90	625.78	618.49
80.9481	44.22	45.94	37.60	0.228	6857.4	67.09	21429.2	0.320	581.13	627.08	619.77
80.9980	44.28	46.01	37.60	0.228	6864.6	67.16	21451.8	0.320	582.36	628.37	621.05
81.0480	44.34	46.07	37.60	0.228	6871.8	67.23	21474.4	0.320	583.59	629.66	622.33
81.0980	44.40	46.13	37.60	0.228	6879.0	67.30	21496.8	0.320	584.82	630.95	623.60
81.1480	44.46	46.19	37.60	0.228	6886.0	67.37	21518.7	0.320	586.01	632.21	624.84
81.1980	44.51	46.25	37.60	0.228	6891.3	67.42	21535.3	0.320	586.92	633.17	625.79
81.2480	44.56	46.30	37.60	0.228	6895.7	67.47	21549.2	0.320	587.69	633.98	626.60
81.2980	44.60	46.34	37.60	0.228	6899.8	67.51	21561.7	0.320	588.37	634.72	627.32
81.3480	44.64	46.38	37.60	0.228	6903.5	67.54	21573.6	0.320	589.02	635.41	628.00
81.3979	44.67	46.42	37.60	0.228	6907.2	67.58	21585.1	0.320	589.65	636.07	628.66
81.4479	44.70	46.45	37.60	0.228	6910.8	67.62	21596.4	0.320	590.28	636.73	629.31
81.4979	44.73	46.48	37.60	0.228	6914.4	67.65	21607.6	0.320	590.89	637.37	629.95
81.5479	44.76	46.51	37.60	0.228	6918.0	67.69	21618.8	0.320	591.51	638.02	630.58
81.5979	44.78	46.54	37.60	0.228	6921.6	67.72	21629.9	0.320	592.12	638.65	631.21
81.6479	44.81	46.56	37.60	0.228	6925.1	67.76	21641.0	0.320	592.73	639.29	631.84
81.6979	44.83	46.59	37.60	0.228	6928.7	67.79	21652.1	0.320	593.33	639.92	632.46
81.7479	44.83	46.59	37.60	0.228	6932.9	67.83	21665.2	0.320	594.05	640.65	633.18
81.7979	44.84	46.60	37.60	0.228	6936.7	67.87	21677.2	0.320	594.72	641.32	633.84
81.8478	44.85	46.62	37.60	0.228	6940.4	67.91	21688.8	0.320	595.35	641.97	634.48
81.8978	44.87	46.63	37.60	0.228	6944.0	67.94	21700.1	0.320	595.97	642.60	635.11
81.9478	44.88	46.65	37.60	0.228	6947.6	67.98	21711.2	0.320	596.58	643.23	635.73
81.9978	44.90	46.67	37.60	0.228	6951.1	68.01	21722.3	0.320	597.19	643.86	636.35
82.0478	44.90	46.67	37.60	0.228	6954.6	68.05	21733.3	0.320	597.80	644.47	636.96
82.0978	44.90	46.67	37.60	0.228	6958.6	68.09	21745.5	0.320	598.47	645.15	637.62
82.1478	44.90	46.67	37.60	0.228	6963.0	68.13	21759.3	0.320	599.23	645.90	638.37
82.1978	44.90	46.68	37.60	0.228	6967.6	68.17	21773.7	0.320	600.03	646.71	639.16
82.2477	44.90	46.68	37.60	0.228	6972.4	68.22	21788.6	0.320	600.85	647.53	639.98
82.2977	44.91	46.69	37.60	0.228	6977.2	68.27	21803.7	0.320	601.66	648.37	640.81
82.3477	44.91	46.70	37.60	0.228	6982.0	68.31	21818.8	0.320	602.52	649.21	641.64
82.3977	44.92	46.71	37.60	0.228	6986.9	68.36	21833.9	0.320	603.35	650.06	642.48
82.4477	44.93	46.72	37.60	0.228	6991.7	68.41	21849.1	0.320	604.19	650.91	643.31
82.4977	44.94	46.73	37.60	0.228	6996.6	68.46	21864.3	0.320	605.03	651.76	644.16
82.5477	44.95	46.74	37.60	0.228	7001.4	68.50	21879.4	0.320	605.87	652.61	645.00
82.5977	44.96	46.75	37.60	0.228	7006.3	68.55	21894.5	0.320	606.71	653.46	645.84
82.6476	44.97	46.77	37.60	0.228	7011.1	68.60	21909.7	0.320	607.55	654.32	646.68
82.6976	44.98	46.78	37.60	0.228	7015.9	68.65	21924.8	0.320	608.39	655.17	647.52
82.7476	44.99	46.79	37.60	0.228	7020.6	68.69	21939.9	0.320	609.23	656.02	648.36
82.7976	45.00	46.80	37.60	0.228	7025.6	68.74	21955.0	0.320	610.07	656.87	649.21
82.8476	45.01	46.82	37.60	0.228	7030.4	68.79	21970.1	0.320	610.91	657.73	650.05
82.8976	45.02	46.83	37.60	0.228	7035.3	68.84	21985.2	0.320	611.75	658.58	650.89
82.9476	45.03	46.84	37.60	0.228	7040.1	68.88	22000.3	0.320	612.59	659.44	651.73

MAIN PUMP

TIME SEC	DHM FT	DHM/N**2 FT/RPM**2	NPSPM PSI	NPSHM FT	NPSH/N**2 FT/RPM**2	EATPM	SHPM HP	TURQM FT-LB
80.4982	18644.9	0.41500E-04	27.72	909.2	0.20238E-05	0.604	3724.0	922.8
80.5482	18697.5	0.41500E-04	27.81	912.1	0.20244E-05	0.604	3739.8	925.4
80.5981	18749.9	0.41500E-04	27.90	914.9	0.20250E-05	0.604	3755.6	928.0
80.6481	18799.9	0.41500E-04	27.98	917.7	0.20258E-05	0.604	3770.7	930.5
80.6981	18845.0	0.41500E-04	28.06	920.4	0.20268E-05	0.604	3784.3	932.7
80.7481	18891.2	0.41500E-04	28.12	922.3	0.20262E-05	0.604	3798.3	935.0
80.7981	18934.4	0.41500E-04	28.19	924.4	0.20260E-05	0.604	3811.4	937.2
80.8481	18976.1	0.41500E-04	28.25	926.4	0.20260E-05	0.604	3824.0	939.2
80.8981	19016.9	0.41500E-04	28.31	928.4	0.20260E-05	0.604	3836.4	941.3
80.9481	19057.3	0.41500E-04	28.37	930.4	0.20261E-05	0.604	3848.6	943.3
80.9980	19097.5	0.41500E-04	28.43	932.5	0.20263E-05	0.604	3860.9	945.3
81.0480	19137.7	0.41500E-04	28.50	934.5	0.20264E-05	0.604	3873.1	947.3
81.0980	19177.7	0.41500E-04	28.56	936.5	0.20266E-05	0.604	3885.3	949.2
81.1480	19216.8	0.41500E-04	28.62	938.5	0.20267E-05	0.604	3897.2	951.2
81.1980	19246.4	0.41500E-04	28.67	940.3	0.20275E-05	0.604	3906.2	952.7
81.2480	19271.3	0.41500E-04	28.73	941.9	0.20285E-05	0.604	3913.8	953.9
81.2980	19293.7	0.41500E-04	28.77	943.4	0.20292E-05	0.604	3920.7	955.0
81.3480	19314.9	0.41500E-04	28.81	944.7	0.20298E-05	0.604	3927.2	956.1
81.3979	19335.5	0.41500E-04	28.85	945.9	0.20302E-05	0.604	3933.5	957.1
81.4479	19355.8	0.41500E-04	28.88	947.0	0.20304E-05	0.604	3939.7	958.1
81.4979	19375.9	0.41500E-04	28.91	948.0	0.20304E-05	0.604	3945.8	959.1
81.5479	19395.9	0.41500E-04	28.94	948.9	0.20302E-05	0.604	3952.0	960.1
81.5979	19415.9	0.41500E-04	28.96	949.8	0.20300E-05	0.604	3958.1	961.1
81.6479	19435.8	0.41500E-04	28.99	950.6	0.20297E-05	0.604	3964.2	962.1
81.6979	19455.7	0.41500E-04	29.01	951.4	0.20294E-05	0.604	3970.3	963.1
81.7479	19479.2	0.41500E-04	29.02	951.6	0.20273E-05	0.604	3977.5	964.2
81.7979	19500.9	0.41500E-04	29.03	951.9	0.20257E-05	0.604	3984.2	965.3
81.8478	19521.7	0.41500E-04	29.04	952.3	0.20245E-05	0.604	3990.5	966.3
81.8978	19542.0	0.41500E-04	29.06	952.8	0.20234E-05	0.604	3996.8	967.4
81.9478	19562.1	0.41500E-04	29.08	953.4	0.20225E-05	0.604	4002.9	968.3
81.9978	19582.0	0.41500E-04	29.09	954.0	0.20217E-05	0.604	4009.1	969.3
82.0478	19601.9	0.41500E-04	29.10	954.1	0.20200E-05	0.604	4015.2	970.3
82.0978	19624.0	0.41500E-04	29.10	954.1	0.20178E-05	0.604	4022.0	971.4
82.1478	19648.8	0.41500E-04	29.10	954.2	0.20153E-05	0.604	4029.6	972.6
82.1978	19675.0	0.41500E-04	29.10	954.3	0.20129E-05	0.604	4037.7	973.9
82.2477	19701.9	0.41500E-04	29.11	954.5	0.20106E-05	0.604	4045.9	975.3
82.2977	19729.1	0.41500E-04	29.12	954.8	0.20083E-05	0.604	4054.3	976.6
82.3477	19756.4	0.41500E-04	29.13	955.0	0.20061E-05	0.604	4062.8	978.0
82.3977	19783.9	0.41500E-04	29.14	955.4	0.20040E-05	0.604	4071.3	979.3
82.4477	19811.4	0.41500E-04	29.15	955.7	0.20020E-05	0.604	4079.7	980.7
82.4977	19838.9	0.41500E-04	29.16	956.1	0.19999E-05	0.604	4088.3	982.1
82.5477	19866.4	0.41500E-04	29.17	956.4	0.19980E-05	0.604	4096.8	983.4
82.5977	19893.9	0.41500E-04	29.18	956.8	0.19960E-05	0.604	4105.3	984.8
82.6476	19921.4	0.41500E-04	29.19	957.2	0.19941E-05	0.604	4113.8	986.1
82.6976	19948.9	0.41500E-04	29.21	957.7	0.19922E-05	0.604	4122.3	987.5
82.7476	19976.4	0.41500E-04	29.22	958.1	0.19903E-05	0.604	4130.9	988.9
82.7976	20004.0	0.41500E-04	29.23	958.5	0.19885E-05	0.604	4139.4	990.2
82.8476	20031.5	0.41500E-04	29.24	958.9	0.19866E-05	0.604	4148.0	991.6
82.8976	20059.0	0.41500E-04	29.26	959.3	0.19848E-05	0.604	4156.5	993.0
82.9476	20086.5	0.41500E-04	29.27	959.8	0.19830E-05	0.604	4165.1	994.3

APPENDIX B

INDUCER TURBINE

TIME SEC	PTTII PSIA	TTII DEG-R	PTEI PSIA	PRI	WT LB/SEC	FPI	DHTI BTU/LB	C0I FT/SEC	UC0I	EATTI	SHPTI HP
80.4982	68.48	440.2	32.54	2.105	7.96	2.440	15.8	3851.8	0.095	0.053	177.8
80.5482	68.70	440.2	32.60	2.107	7.99	2.440	15.8	3854.7	0.095	0.053	178.9
80.5981	68.89	440.1	32.66	2.109	8.01	2.440	15.9	3856.4	0.096	0.053	179.9
80.6481	69.06	440.1	32.72	2.111	8.03	2.440	15.9	3857.9	0.096	0.053	180.7
80.6981	69.14	440.0	32.77	2.110	8.04	2.440	15.9	3856.3	0.096	0.054	181.2
80.7481	69.30	439.9	32.83	2.111	8.06	2.440	16.0	3857.8	0.096	0.054	182.0
80.7981	69.47	439.9	32.88	2.113	8.08	2.440	16.0	3859.3	0.096	0.054	182.8
80.8481	69.64	439.8	32.94	2.114	8.10	2.440	16.0	3860.8	0.096	0.054	183.6
80.8981	69.80	439.8	32.99	2.116	8.12	2.440	16.0	3862.3	0.096	0.054	184.4
80.9481	69.97	439.8	33.04	2.118	8.14	2.440	16.1	3864.7	0.096	0.054	185.2
80.9980	70.14	439.7	33.09	2.119	8.16	2.440	16.1	3866.2	0.096	0.054	186.0
81.0480	70.30	439.7	33.15	2.121	8.18	2.440	16.1	3867.7	0.097	0.054	186.8
81.0980	70.46	439.7	33.20	2.122	8.20	2.440	16.2	3869.1	0.097	0.054	187.5
81.1480	70.54	439.6	33.23	2.123	8.21	2.440	16.2	3869.8	0.097	0.054	188.1
81.1980	70.63	439.6	33.25	2.124	8.22	2.440	16.2	3870.6	0.097	0.054	188.6
81.2480	70.71	439.6	33.28	2.125	8.23	2.440	16.2	3871.4	0.097	0.054	189.0
81.2980	70.79	439.6	33.31	2.125	8.24	2.440	16.3	3872.2	0.097	0.054	189.5
81.3480	70.88	439.6	33.33	2.126	8.25	2.440	16.3	3873.0	0.097	0.054	189.9
81.3979	70.96	439.6	33.36	2.127	8.26	2.440	16.3	3873.9	0.097	0.054	190.4
81.4479	71.04	439.6	33.39	2.128	8.27	2.440	16.3	3874.7	0.097	0.054	190.8
81.4979	71.13	439.6	33.42	2.128	8.28	2.440	16.3	3875.5	0.097	0.054	191.2
81.5479	71.21	439.6	33.44	2.129	8.29	2.440	16.3	3876.3	0.097	0.054	191.6
81.5979	71.29	439.6	33.47	2.130	8.30	2.440	16.4	3877.1	0.097	0.054	192.0
81.6479	71.37	439.6	33.50	2.131	8.31	2.440	16.4	3877.8	0.097	0.055	192.4
81.6979	71.37	439.5	33.53	2.129	8.31	2.440	16.4	3875.5	0.098	0.055	192.5
81.7479	71.45	439.5	33.55	2.130	8.32	2.440	16.4	3876.3	0.098	0.055	192.8
81.7979	71.53	439.5	33.58	2.130	8.33	2.440	16.4	3877.0	0.098	0.055	193.2
81.8478	71.62	439.5	33.61	2.131	8.34	2.440	16.4	3877.7	0.098	0.055	193.6
81.8978	71.70	439.4	33.64	2.132	8.35	2.440	16.4	3878.5	0.098	0.055	193.9
81.9478	71.78	439.4	33.66	2.132	8.36	2.440	16.4	3879.2	0.098	0.055	194.3
81.9978	71.87	439.4	33.68	2.134	8.37	2.440	16.5	3880.8	0.098	0.055	194.8
82.0478	71.97	439.4	33.71	2.135	8.38	2.440	16.5	3881.6	0.098	0.055	195.2
82.0978	72.08	439.4	33.75	2.136	8.39	2.440	16.5	3882.8	0.098	0.055	195.7
82.1478	72.20	439.4	33.79	2.137	8.40	2.440	16.5	3883.9	0.098	0.055	196.2
82.1978	72.31	439.4	33.83	2.138	8.42	2.440	16.5	3884.8	0.098	0.055	196.7
82.2477	72.43	439.3	33.86	2.139	8.43	2.440	16.5	3885.7	0.098	0.055	197.3
82.2977	72.54	439.3	33.90	2.140	8.45	2.440	16.6	3886.7	0.098	0.055	197.8
82.3477	72.66	439.3	33.94	2.141	8.46	2.440	16.6	3887.7	0.098	0.055	198.3
82.3977	72.77	439.3	33.98	2.142	8.47	2.440	16.6	3888.6	0.098	0.055	198.9
82.4477	72.89	439.2	34.02	2.143	8.49	2.440	16.6	3889.6	0.098	0.055	199.4
82.4977	73.00	439.2	34.06	2.144	8.50	2.440	16.6	3890.5	0.098	0.055	200.0
82.5477	73.12	439.2	34.09	2.145	8.51	2.440	16.6	3891.5	0.098	0.055	200.5
82.5977	73.23	439.2	34.13	2.146	8.53	2.440	16.7	3892.4	0.098	0.055	201.1
82.6476	73.35	439.2	34.17	2.147	8.54	2.440	16.7	3893.5	0.098	0.055	201.6
82.6976	73.47	439.2	34.21	2.148	8.55	2.440	16.7	3894.5	0.099	0.055	202.2
82.7476	73.58	439.1	34.25	2.149	8.57	2.440	16.7	3895.5	0.099	0.055	202.7
82.7976	73.70	439.1	34.29	2.149	8.58	2.440	16.7	3896.5	0.099	0.055	203.3
82.8476	73.81	439.1	34.32	2.150	8.59	2.440	16.8	3897.5	0.099	0.055	203.8
82.8976	73.93	439.1	34.36	2.151	8.61	2.440	16.8	3898.5	0.099	0.055	204.4
82.9476	74.04	439.1	34.40	2.152	8.62	2.440	16.8	3899.5	0.099	[illegible]	204.[illegible]

INDUCER TURBINE

TIME SEC	TORQIT FT-LB
80.4982	116.8
80.5482	117.3
80.5981	117.7
80.6481	118.0
80.6981	118.1
80.7481	118.5
80.7981	118.8
80.8481	119.2
80.8981	119.5
80.9481	119.9
80.9980	120.2
81.0480	120.5
81.0980	120.9
81.1480	121.0
81.1980	121.2
81.2480	121.4
81.2980	121.6
81.3480	121.7
81.3979	121.9
81.4479	122.1
81.4979	122.3
81.5479	122.4
81.5979	122.6
81.6479	122.8
81.6979	122.7
81.7479	122.9
81.7979	123.0
81.8478	123.2
81.8978	123.4
81.9478	123.5
81.9978	123.7
82.0478	123.9
82.0978	124.2
82.1478	124.4
82.1978	124.7
82.2477	124.9
82.2977	125.1
82.3477	125.4
82.3977	125.6
82.4477	125.8
82.4977	126.1
82.5477	126.3
82.5977	126.5
82.6476	126.8
82.6976	127.0
82.7476	127.2
82.7976	127.5
82.8476	127.7
82.8976	128.0
82.9476	128.2

MAIN TURBINE

TIME SEC	PTTIM PSIA	TTIM DEG-R	PTTEM PSIA	PRM	WT LB/SEC	FFM	DHTM BTU/LB	COM FT/SEC	UCOM	EATTM	SHPTM HP
80.4982	303.63	532.8	68.48	4.434	7.96	0.605	332.9	5699.2	0.177	0.513	3748.8
80.5482	304.59	532.8	68.70	4.434	7.98	0.605	333.3	5699.4	0.177	0.514	3764.5
80.5981	305.47	532.9	68.89	4.434	8.01	0.605	333.6	5699.7	0.177	0.514	3779.2
80.6481	306.20	532.9	69.06	4.434	8.02	0.605	334.0	5700.0	0.177	0.515	3792.0
80.6981	306.94	533.0	69.14	4.440	8.04	0.605	334.4	5702.2	0.178	0.515	3806.1
80.7481	307.68	533.0	69.30	4.440	8.06	0.605	334.7	5702.4	0.178	0.515	3818.6
80.7981	308.42	533.0	69.47	4.440	8.08	0.605	335.0	5702.7	0.178	0.516	3831.0
80.8481	309.16	533.1	69.64	4.440	8.10	0.605	335.3	5702.9	0.178	0.516	3843.2
80.8981	309.90	533.1	69.80	4.440	8.12	0.605	335.6	5703.2	0.178	0.517	3855.4
80.9481	310.64	533.2	69.97	4.440	8.14	0.605	335.9	5703.5	0.179	0.517	3867.6
80.9980	311.38	533.2	70.14	4.440	8.16	0.605	336.1	5703.7	0.179	0.517	3879.8
81.0480	312.11	533.2	70.30	4.440	8.18	0.605	336.4	5704.0	0.179	0.518	3891.9
81.0980	312.82	533.3	70.46	4.440	8.20	0.605	336.7	5704.2	0.179	0.518	3903.7
81.1480	313.18	533.3	70.54	4.440	8.20	0.605	336.9	5704.4	0.179	0.518	3911.1
81.1980	313.55	533.3	70.63	4.440	8.21	0.605	337.1	5704.7	0.179	0.519	3917.9
81.2480	313.92	533.4	70.71	4.440	8.22	0.605	337.3	5704.9	0.179	0.519	3924.4
81.2980	314.29	533.4	70.79	4.440	8.23	0.605	337.5	5705.1	0.180	0.519	3930.7
81.3480	314.66	533.5	70.88	4.440	8.24	0.605	337.6	5705.3	0.180	0.519	3936.9
81.3979	315.03	533.5	70.96	4.440	8.25	0.605	337.7	5705.5	0.180	0.520	3943.0
81.4479	315.40	533.5	71.04	4.440	8.26	0.605	337.9	5705.8	0.180	0.520	3949.2
81.4979	315.77	533.6	71.13	4.440	8.27	0.605	338.0	5706.0	0.180	0.520	3955.3
81.5479	316.13	533.6	71.21	4.440	8.28	0.605	338.2	5706.2	0.180	0.520	3961.4
81.5979	316.50	533.6	71.29	4.440	8.29	0.605	338.3	5706.3	0.180	0.520	3967.5
81.6479	316.87	533.7	71.37	4.440	8.30	0.605	338.4	5706.5	0.180	0.520	3973.6
81.6979	317.24	533.7	71.37	4.445	8.31	0.605	338.7	5708.6	0.180	0.520	3981.4
81.7479	317.61	533.7	71.45	4.445	8.32	0.605	338.9	5708.7	0.180	0.521	3987.8
81.7979	317.98	533.7	71.53	4.445	8.33	0.605	339.0	5708.9	0.180	0.521	3994.0
81.8478	318.35	533.8	71.62	4.445	8.34	0.605	339.1	5709.0	0.181	0.521	4000.1
81.8978	318.72	533.8	71.70	4.445	8.35	0.605	339.3	5709.2	0.181	0.521	4006.2
81.9478	319.08	533.8	71.78	4.445	8.36	0.605	339.4	5709.4	0.181	0.521	4012.4
81.9978	319.45	533.8	71.87	4.445	8.36	0.605	339.5	5709.5	0.181	0.522	4018.5
82.0478	319.90	533.9	71.97	4.445	8.38	0.605	339.7	5709.7	0.181	0.522	4025.6
82.0978	320.42	533.9	72.08	4.445	8.39	0.605	339.8	5709.9	0.181	0.522	4033.7
82.1478	320.93	533.9	72.20	4.445	8.40	0.605	340.0	5710.0	0.181	0.522	4042.0
82.1978	321.44	534.0	72.31	4.445	8.42	0.605	340.2	5710.2	0.181	0.522	4050.3
82.2477	321.95	534.0	72.43	4.445	8.43	0.605	340.3	5710.4	0.181	0.523	4058.8
82.2977	322.46	534.0	72.54	4.445	8.44	0.605	340.5	5710.6	0.181	0.523	4067.2
82.3477	322.98	534.0	72.66	4.445	8.46	0.605	340.7	5710.7	0.182	0.523	4075.7
82.3977	323.49	534.1	72.77	4.445	8.47	0.605	340.9	5710.9	0.182	0.523	4084.2
82.4477	324.00	534.1	72.89	4.445	8.48	0.605	341.0	5711.1	0.182	0.524	4092.7
82.4977	324.51	534.1	73.00	4.445	8.50	0.605	341.2	5711.2	0.182	0.524	4101.2
82.5477	325.03	534.1	73.12	4.445	8.51	0.605	341.4	5711.4	0.182	0.524	4109.7
82.5977	325.54	534.2	73.23	4.445	8.52	0.605	341.6	5711.6	0.182	0.524	4118.2
82.6476	326.05	534.2	73.35	4.445	8.53	0.605	341.8	5711.8	0.182	0.525	4126.8
82.6976	326.56	534.2	73.47	4.445	8.55	0.605	341.9	5712.1	0.182	0.525	4135.3
82.7476	327.07	534.3	73.58	4.445	8.56	0.605	342.1	5712.3	0.183	0.525	4143.8
82.7976	327.59	534.3	73.70	4.445	8.57	0.605	342.3	5712.6	0.183	0.525	4152.4
82.8476	328.10	534.4	73.81	4.445	8.59	0.605	342.5	5712.8	0.183	0.525	4160.9
82.8976	328.61	534.4	73.93	4.445	8.60	0.605	342.7	5713.0	0.183	0.526	4169.5
82.9476	329.12	534.4	74.04	4.445	8.61	0.605	342.9	5713.3	0.183	0.526	4178.1

MAIN TURBINE

TIME SEC	TORQMT FT-LB
80.4982	928.9
80.5482	931.5
80.5981	933.8
80.6481	935.7
80.6981	938.1
80.7481	940.0
80.7981	942.0
80.8481	944.0
80.8981	945.9
80.9481	947.9
80.9980	949.9
81.0480	951.9
81.0980	953.7
81.1480	954.6
81.1980	955.5
81.2480	956.5
81.2980	957.5
81.3480	958.4
81.3979	959.4
81.4479	960.4
81.4979	961.4
81.5479	962.4
81.5979	963.4
81.6479	964.4
81.6979	965.8
81.7479	966.7
81.7979	967.7
81.8478	968.7
81.8978	969.6
81.9478	970.6
81.9978	971.6
82.0478	972.8
82.0978	974.2
82.1478	975.6
82.1978	977.0
82.2477	978.4
82.2977	979.7
82.3477	981.1
82.3977	982.5
82.4477	983.8
82.4977	985.2
82.5477	986.5
82.5977	987.9
82.6476	989.3
82.6976	990.6
82.7476	992.0
82.7976	993.3
82.8476	994.7
82.8976	996.1
82.9476	997.4

APPENDIX B

INDUCER AND SUCTION LINE

TIME SEC	PSLI PSIA	PII PSIA	TII DEG-R	SVI FT**3/LB	WSLI LB/SEC	QII GPM	WI LB/SEC	PTII PSIA	NI RPM	Q/NI GAL/REV	DPI PSI
82.9976	19.99	19.66	37.60	0.229	68.9	7071.79	68.93	20.1	8402.9	0.84	26.80
83.0475	19.96	19.63	37.60	0.229	69.0	7077.39	68.99	20.0	8408.5	0.84	26.83
83.0975	19.93	19.60	37.60	0.229	69.0	7082.27	69.03	20.0	8414.3	0.84	26.86
83.1475	19.89	19.56	37.60	0.229	69.1	7086.46	69.07	20.0	8420.0	0.84	26.89
83.1975	19.86	19.53	37.60	0.229	69.1	7090.32	69.11	19.9	8425.6	0.84	26.93
83.2475	19.82	19.49	37.60	0.229	69.1	7094.02	69.15	19.9	8431.1	0.84	26.96
83.2975	19.79	19.46	37.60	0.229	69.2	7097.64	69.18	19.9	8436.5	0.84	27.00
83.3475	19.76	19.42	37.60	0.229	69.2	7101.21	69.22	19.8	8441.9	0.84	27.03
83.3975	19.72	19.39	37.60	0.229	69.3	7104.75	69.25	19.8	8447.2	0.84	27.07
83.4474	19.69	19.36	37.60	0.229	69.3	7108.29	69.28	19.8	8452.5	0.84	27.10
83.4974	19.65	19.32	37.60	0.229	69.3	7111.83	69.32	19.7	8457.7	0.84	27.13
83.5474	19.62	19.29	37.60	0.229	69.4	7115.36	69.35	19.7	8463.0	0.84	27.17
83.5974	19.59	19.25	37.60	0.229	69.4	7118.87	69.39	19.7	8468.2	0.84	27.20
83.6474	19.55	19.22	37.60	0.229	69.4	7122.40	69.42	19.6	8473.4	0.84	27.23
83.6974	19.52	19.19	37.60	0.229	69.5	7125.91	69.46	19.6	8478.5	0.84	27.27
83.7474	19.49	19.15	37.60	0.229	69.5	7129.43	69.49	19.6	8483.7	0.84	27.30
83.7974	19.45	19.12	37.60	0.229	69.5	7132.94	69.52	19.5	8488.9	0.84	27.33
83.8474	19.42	19.08	37.60	0.229	69.6	7136.46	69.56	19.5	8494.0	0.84	27.36
83.8973	19.38	19.05	37.60	0.229	69.6	7139.97	69.59	19.5	8499.2	0.84	27.40
83.9473	19.35	19.02	37.60	0.229	69.6	7143.47	69.63	19.4	8504.3	0.84	27.43
83.9973	19.32	18.98	37.60	0.229	69.7	7146.98	69.66	19.4	8509.4	0.84	27.46
84.0473	19.28	18.94	37.60	0.229	69.7	7150.50	69.69	19.3	8514.6	0.84	27.49
84.0973	19.23	18.89	37.60	0.229	69.7	7152.32	69.71	19.3	8518.6	0.84	27.52
84.1473	19.18	18.84	37.60	0.229	69.7	7153.18	69.72	19.2	8521.5	0.84	27.54
84.1973	19.13	18.79	37.60	0.229	69.7	7153.58	69.72	19.2	8523.7	0.84	27.56
84.2473	19.08	18.74	37.60	0.229	69.7	7153.75	69.72	19.1	8525.2	0.84	27.56
84.2972	19.03	18.70	37.60	0.229	69.7	7153.81	69.72	19.1	8526.2	0.84	27.57
84.3472	18.99	18.65	37.60	0.229	69.7	7153.82	69.72	19.1	8526.9	0.84	27.57
84.3972	18.94	18.60	37.60	0.229	69.7	7153.79	69.72	19.0	8527.3	0.84	27.57
84.4472	18.89	18.55	37.60	0.229	69.7	7153.75	69.72	19.0	8527.4	0.84	27.57
84.4972	18.84	18.50	37.60	0.229	69.7	7153.71	69.72	18.9	8527.4	0.84	27.56
84.5472	18.79	18.46	37.60	0.229	69.7	7153.66	69.72	18.9	8527.3	0.84	27.56
84.5972	18.75	18.41	37.60	0.229	69.7	7153.61	69.72	18.8	8527.1	0.84	27.55
84.6472	18.70	18.36	37.60	0.229	69.7	7153.56	69.72	18.8	8526.8	0.84	27.54
84.6971	18.65	18.31	37.60	0.229	69.7	7153.51	69.72	18.7	8526.4	0.84	27.53
84.7471	18.60	18.26	37.60	0.229	69.7	7153.46	69.72	18.7	8526.1	0.84	27.52
84.7971	18.55	18.22	37.60	0.229	69.7	7153.41	69.72	18.6	8525.7	0.84	27.52
84.8471	18.50	18.17	37.60	0.229	69.7	7153.36	69.72	18.6	8525.2	0.84	27.51
84.8971	18.46	18.12	37.60	0.229	69.7	7153.30	69.71	18.5	8524.8	0.84	27.50
84.9471	18.41	18.07	37.60	0.229	69.7	7153.25	69.71	18.5	8524.3	0.84	27.49
84.9971	18.36	18.02	37.60	0.229	69.7	7153.20	69.71	18.4	8523.9	0.84	27.48

INDUCER AND SUCTION LINE

TIME SEC	PTIE PSIA	PIE PSIA	DHI FT	DHI/N**2 FT/RPM**2	NPSPI PSI	NPSHI FT	NPSH/N**2 FT/RPM**2	EATPI	SHPI HP	TORQI FT-LB
82.9976	46.86	45.04	882.1	0.12492E-04	2.49	81.8	0.11587E-05	0.542	203.8	127.4
83.0475	46.85	45.03	883.0	0.12489E-04	2.45	80.7	0.11414E-05	0.542	204.2	127.6
83.0975	46.85	45.03	884.1	0.12487E-04	2.42	79.6	0.11241E-05	0.542	204.7	127.8
83.1475	46.85	45.03	885.2	0.12486E-04	2.38	78.5	0.11068E-05	0.542	205.1	128.0
83.1975	46.85	45.03	886.4	0.12486E-04	2.35	77.4	0.10897E-05	0.542	205.6	128.1
83.2475	46.85	45.03	887.6	0.12486E-04	2.32	76.2	0.10727E-05	0.542	206.0	128.3
83.2975	46.85	45.02	888.7	0.12486E-04	2.28	75.1	0.10557E-05	0.542	206.4	128.5
83.3475	46.86	45.02	889.8	0.12486E-04	2.25	74.0	0.10388E-05	0.541	206.8	128.7
83.3975	46.86	45.02	890.9	0.12486E-04	2.22	72.9	0.10220E-05	0.541	207.2	128.9
83.4474	46.86	45.02	892.1	0.12486E-04	2.18	71.8	0.10051E-05	0.541	207.7	129.0
83.4974	46.86	45.02	893.2	0.12486E-04	2.15	70.7	0.98840E-06	0.541	208.1	129.2
83.5474	46.85	45.01	894.2	0.12486E-04	2.11	69.6	0.97170E-06	0.541	208.5	129.4
83.5974	46.85	45.01	895.3	0.12486E-04	2.08	68.5	0.95505E-06	0.541	208.9	129.6
83.6474	46.85	45.01	896.4	0.12485E-04	2.05	67.4	0.93843E-06	0.541	209.3	129.7
83.6974	46.85	45.01	897.5	0.12485E-04	2.01	66.3	0.92186E-06	0.540	209.7	129.9
83.7474	46.85	45.00	898.6	0.12485E-04	1.98	65.2	0.90534E-06	0.540	210.1	130.1
83.7974	46.85	45.00	899.7	0.12485E-04	1.95	64.1	0.88885E-06	0.540	210.5	130.2
83.8474	46.85	45.00	900.7	0.12485E-04	1.91	62.9	0.87240E-06	0.540	210.9	130.4
83.8973	46.85	45.00	901.8	0.12484E-04	1.88	61.8	0.85600E-06	0.540	211.3	130.6
83.9473	46.85	44.99	902.9	0.12484E-04	1.84	60.7	0.83962E-06	0.540	211.7	130.8
83.9973	46.85	44.99	904.0	0.12484E-04	1.81	59.6	0.82331E-06	0.540	212.2	130.9
84.0473	46.84	44.98	905.0	0.12483E-04	1.77	58.2	0.80326E-06	0.540	212.6	131.1
84.0973	46.81	44.96	905.9	0.12484E-04	1.72	56.6	0.78044E-06	0.539	212.9	131.3
84.1473	46.79	44.93	906.6	0.12484E-04	1.67	55.0	0.75798E-06	0.539	213.2	131.4
84.1973	46.75	44.89	907.1	0.12485E-04	1.62	53.5	0.73574E-06	0.539	213.4	131.5
84.2473	46.71	44.85	907.4	0.12484E-04	1.58	51.9	0.71368E-06	0.539	213.5	131.5
84.2972	46.67	44.81	907.5	0.12484E-04	1.53	50.3	0.69171E-06	0.539	213.6	131.6
84.3472	46.62	44.76	907.6	0.12482E-04	1.48	48.7	0.66982E-06	0.538	213.7	131.6
84.3972	46.57	44.71	907.5	0.12481E-04	1.43	47.1	0.64799E-06	0.538	213.7	131.6
84.4472	46.52	44.66	907.4	0.12479E-04	1.38	45.5	0.62620E-06	0.538	213.8	131.7
84.4972	46.47	44.61	907.3	0.12477E-04	1.34	44.0	0.60443E-06	0.538	213.8	131.7
84.5472	46.41	44.56	907.1	0.12475E-04	1.29	42.4	0.58267E-06	0.538	213.8	131.7
84.5972	46.36	44.50	906.9	0.12472E-04	1.24	40.8	0.56093E-06	0.538	213.8	131.7
84.6472	46.30	44.45	906.6	0.12470E-04	1.19	39.2	0.53920E-06	0.537	213.8	131.7
84.6971	46.25	44.39	906.4	0.12467E-04	1.14	37.6	0.51746E-06	0.537	213.8	131.7
84.7471	46.19	44.33	906.1	0.12464E-04	1.09	36.0	0.49573E-06	0.537	213.8	131.7
84.7971	46.13	44.28	905.8	0.12462E-04	1.05	34.5	0.47400E-06	0.537	213.8	131.7
84.8471	46.08	44.22	905.5	0.12459E-04	1.00	32.9	0.45226E-06	0.537	213.8	131.7
84.8971	46.02	44.16	905.2	0.12456E-04	0.95	31.3	0.43052E-06	0.537	213.8	131.7
84.9471	45.96	44.10	904.9	0.12454E-04	0.90	29.7	0.40879E-06	0.537	213.8	131.7
84.9971	45.91	44.05	904.6	0.12451E-04	0.85	28.1	0.38703E-06	0.536	213.7	131.7

MAIN PUMP

TIME SEC	FMI PSIA	FTMI PSIA	TMI DEG-R	SVM FT**3/LB	QMI GPM	WP LB/SEC	NM RPM	Q/NM GAL/REV	DPM PSI	PTME PSIA	PME PSIA
82.9976	45.04	46.86	37.60	0.228	7044.9	68.93	22015.4	0.320	613.43	660.29	652.58
83.0475	45.03	46.85	37.60	0.228	7050.5	68.99	22032.7	0.320	614.40	661.25	653.53
83.0975	45.03	46.85	37.60	0.228	7055.3	69.03	22047.8	0.320	615.24	662.09	654.36
83.1475	45.03	46.85	37.60	0.228	7059.5	69.07	22060.8	0.320	615.97	662.82	655.07
83.1975	45.03	46.85	37.60	0.228	7063.3	69.11	22072.8	0.320	616.63	663.49	655.74
83.2475	45.03	46.85	37.60	0.228	7066.9	69.15	22084.2	0.320	617.27	664.13	656.37
83.2975	45.02	46.85	37.60	0.228	7070.5	69.18	22095.4	0.320	617.90	664.75	656.99
83.3475	45.02	46.86	37.60	0.228	7074.0	69.22	22106.4	0.320	618.52	665.37	657.60
83.3975	45.02	46.86	37.60	0.228	7077.6	69.25	22117.4	0.320	619.13	665.98	658.20
83.4474	45.02	46.86	37.60	0.228	7081.1	69.28	22128.3	0.320	619.74	666.60	658.81
83.4974	45.02	46.86	37.60	0.228	7084.6	69.32	22139.2	0.320	620.35	667.21	659.41
83.5474	45.01	46.85	37.60	0.228	7088.0	69.35	22150.1	0.320	620.96	667.82	660.01
83.5974	45.01	46.85	37.60	0.228	7091.5	69.39	22161.0	0.320	621.58	668.43	660.62
83.6474	45.01	46.85	37.60	0.228	7095.0	69.42	22171.9	0.320	622.19	669.04	661.22
83.6974	45.01	46.85	37.60	0.228	7098.5	69.46	22182.8	0.320	622.80	669.65	661.82
83.7474	45.00	46.85	37.60	0.228	7102.0	69.49	22193.7	0.320	623.41	670.26	662.42
83.7974	45.00	46.85	37.60	0.228	7105.4	69.52	22204.5	0.320	624.02	670.87	663.02
83.8474	45.00	46.85	37.60	0.228	7108.9	69.56	22215.4	0.320	624.63	671.48	663.63
83.8973	45.00	46.85	37.60	0.228	7112.4	69.59	22226.3	0.320	625.24	672.09	664.23
83.9473	44.99	46.85	37.60	0.228	7115.9	69.63	22237.1	0.320	625.85	672.70	664.83
83.9973	44.99	46.85	37.60	0.228	7119.3	69.66	22248.0	0.320	626.46	673.30	665.43
84.0473	44.98	46.84	37.60	0.228	7122.8	69.69	22258.8	0.320	627.07	673.91	666.02
84.0973	44.96	46.81	37.60	0.228	7124.6	69.71	22264.4	0.320	627.38	674.20	666.31
84.1473	44.93	46.79	37.60	0.228	7125.5	69.72	22267.0	0.320	627.53	674.32	666.43
84.1973	44.89	46.75	37.60	0.228	7125.8	69.72	22268.3	0.320	627.60	674.35	666.46
84.2473	44.85	46.71	37.60	0.228	7126.0	69.72	22268.8	0.320	627.62	674.34	666.45
84.2972	44.81	46.67	37.60	0.228	7126.1	69.72	22269.0	0.320	627.63	674.30	666.41
84.3472	44.76	46.62	37.60	0.228	7126.1	69.72	22269.0	0.320	627.63	674.25	666.36
84.3972	44.71	46.57	37.60	0.228	7126.1	69.72	22269.0	0.320	627.62	674.20	666.31
84.4472	44.66	46.52	37.60	0.228	7126.0	69.72	22268.9	0.320	627.61	674.14	666.25
84.4972	44.61	46.47	37.60	0.228	7126.0	69.72	22268.8	0.320	627.60	674.07	666.18
84.5472	44.56	46.41	37.60	0.228	7126.0	69.72	22268.7	0.320	627.59	674.01	666.12
84.5972	44.50	46.36	37.60	0.228	7126.0	69.72	22268.6	0.320	627.58	673.94	666.05
84.6472	44.45	46.30	37.60	0.228	7125.9	69.72	22268.5	0.320	627.57	673.88	665.99
84.6971	44.39	46.25	37.60	0.228	7125.9	69.72	22268.4	0.320	627.56	673.81	665.92
84.7471	44.33	46.19	37.60	0.228	7125.9	69.72	22268.3	0.320	627.55	673.74	665.86
84.7971	44.28	46.13	37.60	0.228	7125.8	69.72	22268.2	0.320	627.54	673.68	665.79
84.8471	44.22	46.08	37.60	0.228	7125.8	69.72	22268.1	0.320	627.53	673.61	665.72
84.8971	44.16	46.02	37.60	0.228	7125.8	69.71	22268.0	0.320	627.52	673.54	665.65
84.9471	44.10	45.96	37.60	0.228	7125.7	69.71	22267.9	0.320	627.51	673.47	665.59
84.9971	44.05	45.91	37.60	0.228	7125.7	69.71	22267.8	0.320	627.50	673.41	665.52

MAIN PUMP

TIME SEC	DHM FT	DFW/N**2 FT/RPM**2	NPSPM PSI	NPSHM FT	NPSH/N**2 FT/RPM**2	EATPM	SHPM HP	TORQM FT-LB
82.9976	20114.1	0.41500E-04	29.28	960.2	0.19811E-05	0.604	4173.7	995.7
83.0475	20145.7	0.41500E-04	29.28	960.0	0.19777E-05	0.604	4183.5	997.3
83.0975	20173.4	0.41500E-04	29.28	960.0	0.19749E-05	0.604	4192.1	998.6
83.1475	20197.2	0.41500E-04	29.28	960.0	0.19726E-05	0.604	4199.6	999.8
83.1975	20219.1	0.41500E-04	29.28	960.1	0.19706E-05	0.604	4206.4	1000.9
83.2475	20240.0	0.41500E-04	29.28	960.1	0.19686E-05	0.604	4212.9	1001.9
83.2975	20260.5	0.41500E-04	29.28	960.2	0.19667E-05	0.604	4219.3	1002.9
83.3475	20280.8	0.41500E-04	29.28	960.2	0.19648E-05	0.604	4225.6	1003.9
83.3975	20300.9	0.41500E-04	29.28	960.2	0.19628E-05	0.604	4231.9	1004.9
83.4474	20321.0	0.41500E-04	29.28	960.2	0.19609E-05	0.604	4238.2	1005.9
83.4974	20341.0	0.41500E-04	29.28	960.2	0.19589E-05	0.604	4244.5	1006.9
83.5474	20361.1	0.41500E-04	29.28	960.1	0.19570E-05	0.604	4250.8	1007.9
83.5974	20381.1	0.41500E-04	29.28	960.1	0.19550E-05	0.604	4257.0	1008.9
83.6474	20401.2	0.41500E-04	29.28	960.1	0.19530E-05	0.604	4263.3	1009.9
83.6974	20421.2	0.41500E-04	29.28	960.1	0.19510E-05	0.604	4269.6	1010.9
83.7474	20441.2	0.41500E-04	29.28	960.0	0.19491E-05	0.604	4275.9	1011.9
83.7974	20461.2	0.41500E-04	29.28	960.0	0.19471E-05	0.604	4282.2	1012.9
83.8474	20481.2	0.41500E-04	29.28	960.0	0.19451E-05	0.604	4288.4	1013.9
83.8973	20501.3	0.41500E-04	29.28	959.9	0.19432E-05	0.604	4294.7	1014.9
83.9473	20521.3	0.41500E-04	29.27	959.9	0.19412E-05	0.604	4301.0	1015.8
83.9973	20541.3	0.41500E-04	29.27	959.9	0.19392E-05	0.604	4307.3	1016.8
84.0473	20561.3	0.41500E-04	29.26	959.5	0.19367E-05	0.604	4313.6	1017.8
84.0973	20571.7	0.41500E-04	29.24	958.8	0.19342E-05	0.604	4316.9	1018.3
84.1473	20576.6	0.41500E-04	29.21	957.9	0.19319E-05	0.604	4318.4	1018.6
84.1973	20578.8	0.41500E-04	29.18	956.8	0.19295E-05	0.604	4319.1	1018.7
84.2473	20579.8	0.41500E-04	29.14	955.5	0.19268E-05	0.604	4319.4	1018.7
84.2972	20580.2	0.41500E-04	29.10	954.1	0.19239E-05	0.604	4319.5	1018.7
84.3472	20580.2	0.41500E-04	29.05	952.6	0.19208E-05	0.604	4319.5	1018.7
84.3972	20580.1	0.41500E-04	29.00	951.0	0.19176E-05	0.604	4319.4	1018.7
84.4472	20580.0	0.41500E-04	28.95	949.3	0.19142E-05	0.604	4319.3	1018.7
84.4972	20579.8	0.41500E-04	28.90	947.5	0.19108E-05	0.604	4319.2	1018.7
84.5472	20579.7	0.41500E-04	28.84	945.8	0.19072E-05	0.604	4319.2	1018.7
84.5972	20579.5	0.41500E-04	28.79	944.0	0.19036E-05	0.604	4319.1	1018.7
84.6472	20579.3	0.41500E-04	28.73	942.2	0.19000E-05	0.604	4319.0	1018.6
84.6971	20579.1	0.41500E-04	28.68	940.3	0.18963E-05	0.604	4318.9	1018.6
84.7471	20578.9	0.41500E-04	28.62	938.5	0.18926E-05	0.604	4318.8	1018.6
84.7971	20578.8	0.41500E-04	28.56	936.6	0.18889E-05	0.604	4318.7	1018.6
84.8471	20578.6	0.41500E-04	28.51	934.8	0.18851E-05	0.604	4318.6	1018.6
84.8971	20578.4	0.41500E-04	28.45	932.9	0.18814E-05	0.604	4318.5	1018.6
84.9471	20578.2	0.41500E-04	28.39	931.0	0.18776E-05	0.604	4318.4	1018.5
84.9971	20578.0	0.41500E-04	28.33	929.2	0.18739E-05	0.604	4318.3	1018.5

INDUCER TURBINE

TIME SEC	PTTII PSIA	TTII DEG-R	PTEI PSIA	PRI	WT LB/SEC	FPI	DHTI BTU/LB	C0I FT/SEC	UC0I	EATTI	SHPTI HP
82.9976	74.06	439.0	34.42	2.151	8.62	2.440	16.8	3898.2	0.099	0.055	205.1
83.0475	74.16	439.0	34.46	2.152	8.64	2.440	16.8	3899.0	0.099	0.055	205.6
83.0975	74.24	439.0	34.48	2.153	8.65	2.440	16.8	3899.7	0.099	0.055	206.0
83.1475	74.33	439.0	34.51	2.154	8.66	2.440	16.9	3900.5	0.099	0.055	206.4
83.1975	74.41	439.0	34.54	2.154	8.67	2.440	16.9	3901.2	0.099	0.055	206.8
83.2475	74.49	439.0	34.57	2.155	8.67	2.440	16.9	3902.0	0.099	0.056	207.2
83.2975	74.58	439.0	34.59	2.156	8.68	2.440	16.9	3902.8	0.099	0.056	207.6
83.3475	74.66	439.0	34.62	2.157	8.69	2.440	16.9	3903.5	0.099	0.056	208.0
83.3975	74.74	439.0	34.65	2.157	8.70	2.440	16.9	3904.3	0.099	0.056	208.4
83.4474	74.83	439.0	34.68	2.158	8.71	2.440	16.9	3905.1	0.099	0.056	208.9
83.4974	74.91	439.0	34.70	2.159	8.72	2.440	17.0	3905.8	0.099	0.056	209.3
83.5474	74.99	439.0	34.73	2.159	8.73	2.440	17.0	3906.6	0.099	0.056	209.7
83.5974	75.08	439.0	34.76	2.160	8.74	2.440	17.0	3907.4	0.099	0.056	210.1
83.6474	75.16	439.0	34.78	2.161	8.75	2.440	17.0	3908.1	0.100	0.056	210.5
83.6974	75.24	439.0	34.81	2.161	8.76	2.440	17.0	3908.9	0.100	0.056	210.9
83.7474	75.33	439.0	34.84	2.162	8.77	2.440	17.0	3909.6	0.100	0.056	211.3
83.7974	75.41	439.0	34.87	2.163	8.78	2.440	17.0	3910.4	0.100	0.056	211.7
83.8474	75.50	439.0	34.89	2.164	8.79	2.440	17.1	3911.1	0.100	0.056	212.1
83.8973	75.58	439.0	34.92	2.164	8.80	2.440	17.1	3911.9	0.100	0.056	212.5
83.9473	75.66	439.0	34.95	2.165	8.81	2.440	17.1	3912.6	0.100	0.056	212.9
83.9973	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.4	0.100	0.056	213.3
84.0473	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.4	0.100	0.056	213.5
84.0973	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.4	0.100	0.056	213.6
84.1473	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.3	0.100	0.056	213.7
84.1973	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.3	0.100	0.056	213.7
84.2473	75.75	439.0	34.98	2.166	8.82	2.440	17.1	3913.3	0.100	0.056	213.7
84.2972	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.3	0.100	0.056	213.8
84.3472	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.3972	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.4472	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.4972	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.5472	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.5972	75.74	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.8
84.6472	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.7
84.6971	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.7
84.7471	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.7
84.7971	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.2	0.100	0.056	213.7
84.8471	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.1	0.100	0.056	213.7
84.8971	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.1	0.100	0.056	213.7
84.9471	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.1	0.100	0.056	213.7
84.9971	75.73	439.0	34.97	2.166	8.82	2.440	17.1	3913.1	0.100	0.056	213.6

INDUCER TURBINE

TIME SEC	TORQIT FT-LB
82.9976	128.2
83.0475	128.4
83.0975	128.6
83.1475	128.7
83.1975	128.9
83.2475	129.1
83.2975	129.3
83.3475	129.4
83.3975	129.6
83.4474	129.8
83.4974	129.9
83.5474	130.1
83.5974	130.3
83.6474	130.5
83.6974	130.6
83.7474	130.8
83.7974	131.0
83.8474	131.2
83.8973	131.3
83.9473	131.5
83.9973	131.7
84.0473	131.7
84.0973	131.7
84.1473	131.7
84.1973	131.7
84.2473	131.7
84.2972	131.7
84.3472	131.7
84.3972	131.7
84.4472	131.7
84.4972	131.7
84.5472	131.7
84.5972	131.7
84.6472	131.7
84.6971	131.7
84.7471	131.7
84.7971	131.6
84.8471	131.6
84.8971	131.6
84.9471	131.6
84.9971	131.6

MAIN TURBINE

TIME SEC	PTTIM PSIA	TTIM DEG-R	PTTEM PSIA	PRM	WT LB/SEC	FPM	DHTM BTU/LB	CUM FT/SEC	UCUM	EATTM	SHPTM HP
82.9976	329.63	534.5	74.06	4.451	8.63	0.605	343.2	5715.6	0.183	0.526	4188.6
83.0475	330.08	534.5	74.16	4.451	8.64	0.605	343.4	5715.8	0.183	0.526	4196.6
83.0975	330.45	534.6	74.24	4.451	8.65	0.605	343.6	5716.0	0.183	0.527	4203.4
83.1475	330.82	534.6	74.33	4.451	8.66	0.605	343.7	5716.2	0.183	0.527	4209.9
83.1975	331.19	534.6	74.41	4.451	8.67	0.605	343.9	5716.5	0.183	0.527	4216.3
83.2475	331.56	534.7	74.49	4.451	8.68	0.605	344.0	5716.7	0.184	0.527	4222.6
83.2975	331.94	534.7	74.58	4.451	8.68	0.605	344.2	5716.9	0.184	0.527	4228.9
83.3475	332.31	534.8	74.66	4.451	8.69	0.605	344.3	5717.2	0.184	0.527	4235.1
83.3975	332.68	534.8	74.74	4.451	8.70	0.605	344.4	5717.4	0.184	0.528	4241.4
83.4474	333.05	534.8	74.83	4.451	8.71	0.605	344.6	5717.6	0.184	0.528	4247.7
83.4974	333.42	534.9	74.91	4.451	8.72	0.605	344.7	5717.8	0.184	0.528	4253.9
83.5474	333.80	534.9	74.99	4.451	8.73	0.605	344.9	5718.1	0.184	0.528	4260.2
83.5974	334.17	535.0	75.08	4.451	8.74	0.605	345.0	5718.3	0.184	0.528	4266.5
83.6474	334.54	535.0	75.16	4.451	8.75	0.605	345.1	5718.5	0.184	0.528	4272.8
83.6974	334.91	535.0	75.24	4.451	8.76	0.605	345.3	5718.8	0.184	0.529	4279.0
83.7474	335.28	535.1	75.33	4.451	8.77	0.605	345.4	5719.0	0.184	0.529	4285.3
83.7974	335.66	535.1	75.41	4.451	8.78	0.605	345.5	5719.2	0.184	0.529	4291.6
83.8474	336.03	535.2	75.50	4.451	8.79	0.605	345.7	5719.4	0.185	0.529	4297.9
83.8973	336.40	535.2	75.58	4.451	8.80	0.605	345.8	5719.7	0.185	0.529	4304.2
83.9473	336.77	535.2	75.66	4.451	8.81	0.605	345.9	5719.9	0.185	0.529	4310.5
83.9973	337.14	535.3	75.75	4.451	8.82	0.605	346.1	5720.1	0.185	0.530	4316.8
84.0473	337.16	535.3	75.75	4.451	8.82	0.605	346.2	5720.3	0.185	0.530	4318.5
84.0973	337.16	535.3	75.75	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.2
84.1473	337.15	535.3	75.75	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.5
84.1973	337.15	535.3	75.75	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.5
84.2473	337.14	535.3	75.75	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.5
84.2972	337.13	535.3	75.74	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.5
84.3472	337.13	535.3	75.74	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.4
84.3972	337.12	535.3	75.74	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.3
84.4472	337.12	535.3	75.74	4.451	8.82	0.605	346.3	5720.3	0.185	0.530	4319.3
84.4972	337.11	535.3	75.74	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4319.2
84.5472	337.10	535.3	75.74	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4319.1
84.5972	337.10	535.3	75.74	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4319.0
84.6472	337.09	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.9
84.6971	337.09	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.8
84.7471	337.08	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.7
84.7971	337.07	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.6
84.8471	337.07	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.5
84.8971	337.06	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.4
84.9471	337.06	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.3
84.9971	337.05	535.3	75.73	4.451	8.81	0.605	346.3	5720.3	0.185	0.530	4318.3

MAIN TURBINE

TIME SEC	TCRQMT FT-LB
82.9976	999.3
83.0475	1000.4
83.0975	1001.3
83.1475	1002.3
83.1975	1003.2
83.2475	1004.2
83.2975	1005.2
83.3475	1006.2
83.3975	1007.2
83.4474	1008.2
83.4974	1009.2
83.5474	1010.2
83.5974	1011.1
83.6474	1012.1
83.6974	1013.1
83.7474	1014.1
83.7974	1015.1
83.8474	1016.1
83.8973	1017.1
83.9473	1018.1
83.9973	1019.1
84.0473	1019.0
84.0973	1018.9
84.1473	1018.8
84.1973	1018.8
84.2473	1018.8
84.2972	1018.7
84.3472	1018.7
84.3972	1018.7
84.4472	1018.7
84.4972	1018.7
84.5472	1018.7
84.5972	1018.6
84.6472	1018.6
84.6971	1018.6
84.7471	1018.6
84.7971	1018.6
84.8471	1018.6
84.8971	1018.5
84.9471	1018.5
84.9971	1018.5

HYDROGEN PROPERTIES DECK LISTING

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9 10 11 13 15 16 16 17 17 18 19 20 27 27 27 27 27 26 26 26 26 26 25 25 25
 24.9029  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 36.4823
 0.20788  0.20828  0.21058  0.21305  0.21575  0.21869  0.22187  0.22528
 0.22632
 -132.27  -131.80  -128.88  -125.77  -122.46  -118.96  -115.25  -111.28
 -110.18
   1.186    1.205    1.316    1.427    1.539    1.650    1.761    1.874
   1.905
   4183.    4156.    4068.    3973.    3868.    3776.    3694.    3618.
   3585.
 24.9336  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 37.8000  39.0995
 0.20780  0.20812  0.21042  0.21289  0.21559  0.21853  0.22163  0.22512
 0.22894  0.23196
 -131.97  -131.55  -128.65  -125.53  -122.25  -118.75  -115.02  -111.07
 -106.85  -103.63
   1.186    1.202    1.314    1.425    1.536    1.648    1.759    1.872
   1.985    2.070
   4186.    4163.    4074.    3982.    3877.    3786.    3704.    3625.
   3526.    3457.
 24.9641  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 37.8000  39.6000  41.1497
 0.20772  0.20804  0.21026  0.21281  0.21543  0.21829  0.22147  0.22489
 0.22870  0.23291  0.23697
 -131.67  -131.31  -128.39  -125.30  -122.01  -118.51  -114.80  -110.86
 -106.66  -102.16   -98.04
   1.186    1.201    1.312    1.424    1.534    1.645    1.757    1.869
   1.983    2.099    2.201
   4189.    4169.    4081.    3989.    3884.    3795.    3713.    3635.
   3536.    3441.    3336.
 25.0254  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 37.8000  39.6000  41.4000  43.2000  44.3376
 0.20756  0.20780  0.21003  0.21249  0.21511  0.21797  0.22107  0.22449
 0.22814  0.23236  0.23705  0.24237  0.24618
 -131.10  -130.82  -127.92  -124.83  -121.54  -118.07  -114.38  -110.45
 -106.27  -101.79   -96.99   -91.85   -88.38
   1.187    1.197    1.309    1.420    1.530    1.641    1.752    1.863
   1.977    2.092    2.211    2.333    2.412
   4196.    4179.    4094.    4002.    3904.    3815.    3730.    3651.
   3556.    3464.    3346.    3225.    3143.
 25.0865  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 37.8000  39.6000  41.4000  43.2000  45.0000  46.8000  46.8414
 0.20740  0.20756  0.20979  0.21225  0.21479  0.21766  0.22067  0.22401
 0.22767  0.23180  0.23641  0.24157  0.24769  0.25493  0.25508
 -130.52  -130.35  -127.45  -124.36  -121.10  -117.62  -113.95  -110.03
 -105.87  -101.43   -96.67   -91.56   -86.03   -79.95   -79.80
   1.187    1.194    1.305    1.415    1.526    1.636    1.747    1.859
   1.971    2.086    2.203    2.324    2.450    2.581    2.585
   4202.    4192.    4110.    4018.    3920.    3831.    3749.    3671.
   3576.    3484.    3369.    3254.    3120.    2965.    2962.
 25.1459  25.2000  27.0000  28.8000  30.6000  32.4000  34.2000  36.0000
 37.8000  39.6000  41.4000  43.2000  45.0000  46.8000  48.6000  48.9365
 0.20724  0.20732  0.20955  0.21193  0.21456  0.21734  0.22036  0.22362
 0.22719  0.23124  0.23577  0.24086  0.24674  0.25381  0.26232  0.26414
 -129.95  -129.88  -126.96  -123.89  -120.63  -117.17  -113.50  -109.60
```

-105.46	-101.05	-96.33	-91.26	-85.80	-79.80	-73.17	-71.85
1.188	1.192	1.302	1.412	1.522	1.631	1.742	1.853
1.965	2.079	2.196	2.316	2.439	2.570	2.709	2.737
4205.	4202.	4123.	4032.	3936.	3848.	3766.	3687.
3595.	3503.	3395.	3280.	3149.	2998.	2824.	2782.
25.2071	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	50.7564
0.20709	0.20931	0.21162	0.21424	0.21694	0.21996	0.22322	0.22679
0.23069	0.23514	0.24014	0.24587	0.25262	0.26089	0.27130	0.27368
-129.37	-126.49	-123.44	-120.18	-116.72	-113.08	-109.19	-105.06
-100.68	-95.99	-90.96	-85.54	-79.66	-73.13	-65.75	-64.15
1.188	1.298	1.408	1.517	1.628	1.738	1.848	1.959
2.073	2.189	2.308	2.430	2.559	2.695	2.844	2.876
4212.	4137.	4048.	3953.	3868.	3786.	3704.	3615.
3523.	3418.	3307.	3179.	3034.	2867.	2660.	2618.
25.2665	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
52.3745							
0.20693	0.20907	0.21138	0.21392	0.21662	0.21956	0.22282	0.22632
0.23021	0.23450	0.23943	0.24507	0.25159	0.25945	0.26923	0.28242
0.28401							
-128.79	-126.02	-122.97	-119.71	-116.28	-112.63	-108.77	-104.65
-100.30	-95.63	-90.66	-85.29	-79.48	-73.09	-65.90	-57.50
-56.58							
1.189	1.295	1.405	1.514	1.623	1.733	1.843	1.953
2.067	2.182	2.299	2.421	2.547	2.682	2.827	2.990
3.008							
4222.	4150.	4061.	3969.	3884.	3802.	3720.	3635.
3543.	3441.	3330.	3205.	3067.	2906.	2713.	2480.
2450.							
25.3278	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
53.8380							
0.20677	0.20883	0.21114	0.21360	0.21630	0.21924	0.22242	0.22584
0.22965	0.23395	0.23871	0.24420	0.25055	0.25810	0.26748	0.27964
0.29561							
-128.22	-125.53	-122.48	-119.26	-115.83	-112.18	-108.34	-104.25
-99.92	-95.29	-90.34	-85.03	-79.29	-73.00	-65.98	-57.92
-48.92							
1.189	1.291	1.401	1.510	1.619	1.728	1.837	1.949
2.060	2.175	2.291	2.412	2.538	2.669	2.810	2.968
3.137							
4232.	4163.	4074.	3982.	3900.	3818.	3740.	3654.
3562.	3464.	3356.	3234.	3100.	2942.	2759.	2542.
2289.							
25.3871	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.1717						
0.20661	0.20860	0.21082	0.21336	0.21599	0.21893	0.22203	0.22544
0.22918	0.23339	0.23808	0.24340	0.24960	0.25683	0.26573	0.27710
0.29315	0.30896						
-127.64	-125.06	-122.01	-118.79	-115.38	-111.75	-107.91	-103.84
-99.53	-94.93	-90.02	-84.77	-79.10	-72.89	-66.05	-58.24
-48.84	-41.01						
1.189	1.289	1.407	1.506	1.615	1.724	1.833	1.943
2.054	2.168	2.284	2.404	2.527	2.657	2.795	2.948
3.124	3.267						
4238.	4176.	4091.	3999.	3917.	3835.	3756.	3671.
3582.	3487.	3379.	3261.	3129.	2978.	2801.	2601.
2345.	2125.						

25.4465	27.CCCO	28.8000	30.6000	32.4C00	34.200C	36.0000	37.8000
39.6000	41.4C00	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8CCC	56.4029					
0.20645	0.20836	0.21058	0.21305	C.21567	0.21853	0.22163	0.22505
0.22870	C.23283	0.23744	0.24261	0.24865	0.25564	0.26414	0.27487
0.28933	0.31238	C.32525					
-127.07	-124.59	-121.54	-118.32	-114.91	-111.31	-107.49	-103.44
-99.15	-94.56	-89.70	-84.50	-78.87	-72.79	-66.07	-58.48
-49.56	-37.94	-32.54					
1.190	1.285	1.394	1.502	1.611	1.719	1.828	1.938
2.048	2.162	2.277	2.394	2.517	2.644	2.780	2.929
3.096	3.308	3.404					
4248.	4166.	4104.	4015.	3933.	3851.	3772.	3690.
3602.	3507.	3402.	3287.	3159.	3015.	2847.	2654.
2417.	2106.	1961.					
25.5960	27.C0CC	28.8000	30.6000	32.4C00	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8000	57.6000	59.1047				
0.20613	0.20772	0.20995	0.21241	0.21495	0.21773	0.22075	0.22401
0.22751	0.23148	0.23585	0.24078	C.24642	0.25294	0.26057	0.26994
0.28186	0.29847	0.32597	0.41744				
-125.62	-123.40	-120.37	-117.17	-113.78	-110.20	-106.42	-102.41
-98.17	-93.65	-88.87	-83.77	-78.29	-72.40	-65.96	-58.86
-50.78	-41.12	-28.19	-1.36				
1.192	1.277	1.385	1.492	1.60C	1.708	1.816	1.925
2.034	2.145	2.259	2.374	2.494	2.617	2.747	2.886
3.038	3.214	3.442	3.900				
4268.	4215.	4137.	4051.	3973.	3894.	3812.	3733.
3648.	3559.	3457.	3349.	3228.	3097.	2946.	2772.
2575.	2335.	2014.	1292.				
25.7435	27.CCCO	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
68.400C	70.200C	72.0000					
0.20574	0.20717	0.20939	0.21170	C.21424	0.21694	0.21980	0.22298
0.22640	0.23021	0.23442	0.23911	C.24436	0.25040	0.25747	0.26581
0.27614	0.28941	0.30825	0.34011	C.44994	0.75143	0.90298	1.01590
1.11047	1.19573	1.27433					
-124.19	-122.20	-119.20	-116.02	-112.65	-109.09	-105.33	-101.37
-97.17	-92.73	-88.02	-83.00	-77.65	-71.91	-65.73	-58.97
-51.44	-42.82	-32.46	-18.36	12.47	61.59	80.53	93.62
104.16	113.40	121.76					
1.193	1.269	1.376	1.483	1.591	1.697	1.804	1.912
2.021	2.130	2.241	2.355	2.471	2.592	2.716	2.849
2.990	3.147	3.330	3.571	4.080	4.874	5.172	5.371
5.527	5.660	5.778					
4288.	4245.	4169.	4087.	4009.	3933.	3854.	3779.
3694.	3608.	3513.	3408.	3293.	3169.	3031.	2873.
2700.	2499.	2260.	1945.	1361.	1358.	1423.	1476.
1519.	1558.	1597.					
26.0369	27.0CCC	28.8000	30.6000	32.4000	34.200C	36.0000	37.8000
39.600C	41.4CCC	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.000C	55.8CCO	57.6000	59.4000	61.200C	63.0000	64.8000	66.6000
68.400C	70.2CCC	72.0000					
0.20502	0.20605	C.20820	0.21042	C.21281	0.21535	0.21813	0.22107
C.22433	0.22783	0.23172	0.23601	C.24078	C.24619	0.25214	0.25914
0.26732	0.27726	0.28957	0.30570	C.32851	C.36491	0.43071	0.53719
0.64455	C.73818	C.81533					
-121.33	-119.82	-116.83	-113.69	-110.37	-106.87	-103.16	-99.26

-95.14	-90.81	-86.22	-81.38	-76.24	-70.76	-64.94	-58.67
-51.86	-44.42	-36.06	-26.48	-14.92	0.0	20.71	45.94
66.65	82.43	95.16					
1.196	1.253	1.360	1.465	1.571	1.676	1.782	1.888
1.994	2.102	2.209	2.320	2.431	2.546	2.664	2.786
2.914	3.049	3.198	3.361	3.552	3.792	4.117	4.591
4.808	5.037	5.215					
4330.	4301.	4228.	4156.	4081.	4009.	3930.	3861.
3779.	3700.	3612.	3517.	3415.	3303.	3182.	3051.
2910.	2752.	2575.	2381.	2155.	1902.	1653.	1541.
1535.	1564.	1597.					
26.3268	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
68.4000	70.2000	72.0000					
0.20430	0.20502	0.20701	0.20915	0.21146	0.21392	0.21654	0.21940
0.22242	0.22568	0.22934	0.23323	0.23760	0.24237	0.24777	0.25381
0.26073	0.26875	0.27821	0.28965	0.30396	0.32239	0.34719	0.38160
0.42943	0.48688	0.55324					
-118.47	-117.41	-114.46	-111.37	-108.06	-104.61	-100.96	-97.12
-93.09	-88.83	-84.37	-79.66	-74.66	-69.42	-63.85	-57.92
-51.59	-44.81	-37.40	-29.30	-20.24	-9.96	1.98	16.01
22.24	49.35	65.54					
1.199	1.238	1.343	1.449	1.553	1.657	1.761	1.865
1.969	2.074	2.180	2.288	2.395	2.506	2.618	2.733
2.853	2.576	3.106	3.246	3.395	3.561	3.749	3.962
4.202	4.449	4.676					
4373.	4356.	4284.	4219.	4150.	4078.	4005.	3936.
3861.	3786.	3704.	3615.	3523.	3421.	3313.	3198.
3077.	2942.	2798.	2647.	2480.	2303.	2119.	1948.
1801.	1722.	1692.					
26.6130	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
68.4000	70.2000	72.0000					
0.20367	0.20407	0.20597	0.20804	0.21019	0.21257	0.21503	0.21773
0.22060	0.22369	0.22711	0.23077	0.23474	0.23911	0.24396	0.24936
0.25540	0.26224	0.27002	0.27916	0.28981	0.30268	0.31834	0.33789
0.36236	0.35280	0.42936					
-115.64	-115.02	-112.09	-109.02	-105.78	-102.35	-98.74	-94.97
-90.98	-86.82	-82.45	-77.84	-73.00	-67.92	-62.55	-56.90
-50.90	-44.53	-37.72	-30.41	-22.50	-13.86	-4.37	6.14
17.78	30.52	44.02					
1.201	1.224	1.329	1.432	1.535	1.638	1.741	1.843
1.946	2.049	2.152	2.257	2.362	2.469	2.578	2.688
2.801	2.917	3.036	3.162	3.292	3.432	3.580	3.740
3.913	4.097	4.286					
4419.	4409.	4337.	4278.	4212.	4143.	4074.	4009.
3936.	3868.	3789.	3707.	3622.	3526.	3431.	3326.
3218.	3100.	2975.	2847.	2709.	2568.	2421.	2276.
2139.	2017.	1929.					
26.8955	27.0000	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000
39.6000	41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000
54.0000	55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000
68.4000	70.2000	72.0000					
0.20295	0.20311	0.20494	0.20693	0.20899	0.21130	0.21368	0.21622
0.21893	0.22187	0.22505	0.22846	0.23220	0.23625	0.24070	0.24555
0.25055	0.25651	0.26367	0.27122	0.27996	0.28997	0.30165	0.31548
0.33177	0.35116	0.37397					
-112.80	-112.63	-109.73	-106.68	-103.46	-100.09	-96.53	-92.79

-88.87	-84.77	-80.47	-75.97	-71.25	-66.30	-61.10	-55.66
-49.90	-43.87	-37.45	-30.66	-23.43	-15.69	-7.40	1.53
11.17	21.51	32.54					
1.205	1.210	1.314	1.417	1.519	1.620	1.722	1.823
1.924	2.026	2.128	2.229	2.333	2.436	2.541	2.647
2.756	2.866	2.978	3.094	3.214	3.339	3.469	3.605
3.747	3.897	4.052					
4461.	4458.	4389.	4333.	4271.	4209.	4140.	4078.
4009.	3943.	3868.	3792.	3710.	3625.	3536.	3441.
3343.	3238.	3126.	3011.	2893.	2772.	2647.	2522.
2401.	2286.	2188.					
27.1745	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
70.2000	72.0000						
0.20232	0.20399	0.20589	0.20788	0.21003	0.21233	0.21479	0.21742
0.22020	0.22322	0.22640	0.22989	0.23363	0.23776	0.24221	0.24706
0.25238	0.25834	0.26494	0.27233	0.28067	0.29013	0.30094	0.31325
0.32740	0.34369						
-109.96	-107.36	-104.33	-101.15	-97.81	-94.29	-90.60	-86.74
-82.70	-78.46	-74.05	-69.44	-64.60	-59.54	-54.25	-48.73
-42.91	-36.81	-30.39	-23.63	-16.46	-8.89	-0.85	7.67
16.69	26.21						
1.207	1.299	1.401	1.503	1.603	1.703	1.803	1.904
2.003	2.103	2.203	2.304	2.405	2.507	2.610	2.714
2.821	2.927	3.038	3.150	3.265	3.384	3.506	3.632
3.763	3.897						
4501.	4442.	4386.	4327.	4268.	4205.	4146.	4081.
4015.	3946.	3871.	3795.	3717.	3631.	3543.	3454.
3356.	3257.	3156.	3051.	2942.	2831.	2719.	2611.
2509.	2411.						
27.4500	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
70.2000	72.0000						
0.20168	0.20303	0.20486	0.20677	0.20891	0.21106	0.21344	0.21591
0.21861	0.22139	0.22449	0.22775	0.23124	0.23506	0.23919	0.24364
0.24849	0.25381	0.25969	0.26613	0.27336	0.28131	0.29021	0.30022
0.31151	0.32406						
-107.13	-104.99	-101.99	-98.83	-95.52	-92.03	-88.40	-84.56
-80.59	-76.43	-72.08	-67.56	-62.83	-57.90	-52.74	-47.36
-41.76	-35.89	-29.75	-23.33	-16.59	-9.51	-2.06	5.73
13.92	22.50						
1.209	1.286	1.387	1.487	1.587	1.686	1.785	1.883
1.982	2.080	2.179	2.277	2.376	2.476	2.577	2.677
2.780	2.884	2.988	3.094	3.203	3.315	3.427	3.544
3.661	3.782						
4537.	4488.	4438.	4383.	4327.	4265.	4205.	4146.
4084.	4015.	3946.	3874.	3799.	3723.	3641.	3556.
3467.	3375.	3280.	3185.	3087.	2988.	2887.	2788.
2693.	2604.						
27.7235	28.8000	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
70.2000	72.0000						
0.20105	0.20208	0.20391	0.20574	0.20772	0.20987	0.21217	0.21456
0.21710	0.21980	0.22266	0.22576	0.22910	0.23267	0.23649	0.24062
0.24507	0.24992	0.25524	0.26096	0.26732	0.27424	0.28186	0.29037
0.29967	0.31000						

-104.33	-1C2.63	-99.64	-96.50	-93.22	-89.79	-86.18	-82.41
-78.46	-74.37	-70.10	-65.64	-60.99	-56.17	-51.14	-45.89
-40.45	-34.78	-28.87	-22.71	-16.27	-9.55	-2.55	4.75
12.37	2C.28						
1.213	1.272	1.373	1.472	1.571	1.669	1.767	1.865
1.962	2.C59	2.155	2.252	2.349	2.448	2.546	2.644
2.744	2.843	2.944	3.047	3.150	3.256	3.362	3.470
3.580	3.692						
4576.	4537.	4488.	4432.	4379.	4324.	4268.	4209.
4146.	4084.	4018.	3950.	3877.	3805.	3730.	3648.
3566.	3477.	3392.	3307.	3215.	3126.	3034.	2942.
2854.	2768.						
28.2617	28.8CCC	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
55.8000	57.6CCC	59.4000	61.2000	63.0C00	64.8000	66.6000	68.4000
70.2000	72.0CCC						
0.19985	0.20033	0.20200	0.20383	C.20566	0.20764	0.20971	0.21193
0.21432	0.21678	0.21940	0.22218	C.22520	0.22838	0.23172	0.23538
0.23919	0.24332	0.24777	0.25262	0.25771	0.26335	0.26931	0.27582
0.28290	0.29053						
-98.72	-97.87	-94.95	-91.88	-88.63	-85.24	-81.70	-78.03
-74.17	-70.19	-66.01	-61.70	-57.20	-52.55	-47.71	-42.69
-37.51	-32.11	-26.55	-20.77	-14.71	-8.59	-2.17	4.45
11.30	18.38						
1.218	1.247	1.346	1.444	1.541	1.637	1.733	1.829
1.924	2.C19	2.112	2.207	2.301	2.395	2.489	2.584
2.679	2.773	2.868	2.964	3.060	3.157	3.256	3.354
3.452	3.552						
4645.	4629.	4579.	4530.	4484.	4435.	4379.	4327.
4271.	4212.	4153.	4091.	4025.	3959.	3891.	3818.
3746.	3671.	3595.	3517.	3438.	3359.	3280.	3202.
3123.	3C47.						
28.7910	28.8CCC	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000
41.4000	43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000
55.8000	57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000
70.2000	72.000C						
0.19874	0.19874	0.20033	0.20200	0.20375	C.20558	0.20756	0.20963
0.21177	0.21408	C.21646	0.21909	0.22179	0.22465	0.22767	0.23085
0.23434	0.23792	0.24181	0.24595	C.25032	0.25500	0.26001	0.26534
0.27106	0.27718						
-93.13	-93.11	-90.26	-87.21	-84.03	-80.70	-77.22	-73.60
-69.82	-65.92	-61.85	-57.64	-53.27	-48.75	-44.06	-39.24
-34.23	-29.07	-23.73	-18.23	-12.58	-6.71	-0.70	5.50
11.87	18.42						
1.224	1.224	1.321	1.417	1.513	1.607	1.702	1.796
1.888	1.981	2.073	2.165	2.257	2.348	2.439	2.530
2.622	2.713	2.804	2.894	2.987	3.078	3.169	3.262
3.353	3.445						
4717.	4717.	4668.	4625.	4583.	4537.	4484.	4435.
4383.	4330.	4274.	4219.	4160.	4097.	4035.	3969.
3904.	3835.	3769.	3697.	3628.	3556.	3484.	3415.
3346.	3277.						
29.3093	30.600C	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
43.2000	45.00CC	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
57.6C00	59.4C00	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
72.0000							
0.19763	0.19666	C.20025	0.20192	0.20367	C.20550	0.20748	0.20947
0.21162	0.21384	0.21622	0.21669	C.22131	0.22409	0.22703	0.23013
0.23339	C.23681	0.24046	0.24428	C.24833	0.25262	0.25723	0.26208
0.26716							

-87.59	-85.54	-82.56	-79.42	-76.14	-72.72	-69.16	-65.45
-61.61	-57.62	-53.51	-49.24	-44.83	-40.09	-35.57	-30.73
-25.74	-20.60	-15.31	-9.87	-4.28	1.45	7.33	13.37
19.55							
1.228	1.297	1.392	1.487	1.579	1.673	1.765	1.856
1.946	2.036	2.126	2.216	2.305	2.394	2.483	2.571
2.658	2.747	2.835	2.923	3.009	3.097	3.185	3.271
3.359							
4786.	4750.	4714.	4675.	4632.	4586.	4540.	4488.
4438.	4386.	4333.	4281.	4225.	4166.	4107.	4048.
3986.	3923.	3858.	3795.	3730.	3664.	3602.	3539.
3474.							
29.8167	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
72.0000							
0.19660	0.19715	0.19866	0.20025	0.20192	0.20367	0.20542	0.20732
0.20939	0.21146	0.21368	0.21599	0.21837	0.22091	0.22362	0.22640
0.22934	0.23252	0.23577	0.23919	0.24277	0.24658	0.25055	0.25477
0.25922							
-82.09	-80.85	-77.91	-74.81	-71.57	-68.20	-64.68	-61.04
-57.26	-53.36	-49.31	-45.15	-40.82	-36.38	-31.80	-27.06
-22.22	-17.23	-12.11	-6.84	-1.47	4.05	9.70	15.48
21.41							
1.234	1.274	1.368	1.462	1.553	1.645	1.735	1.825
1.914	2.003	2.092	2.180	2.266	2.353	2.439	2.526
2.611	2.696	2.782	2.866	2.950	3.034	3.118	3.201
3.284							
4852.	4829.	4799.	4763.	4724.	4678.	4635.	4586.
4540.	4494.	4445.	4392.	4340.	4288.	4232.	4176.
4120.	4061.	4002.	3943.	3884.	3825.	3766.	3707.
3651.							
30.3191	30.6000	32.4000	34.2000	36.0000	37.8000	39.6000	41.4000
43.2000	45.0000	46.8000	48.6000	50.4000	52.2000	54.0000	55.8000
57.6000	59.4000	61.2000	63.0000	64.8000	66.6000	68.4000	70.2000
72.0000							
0.19556	0.19580	0.19715	0.19866	0.20025	0.20192	0.20359	0.20542
0.20732	0.20923	0.21130	0.21344	0.21575	0.21805	0.22060	0.22314
0.22584	0.22870	0.23164	0.23474	0.23800	0.24142	0.24499	0.24873
0.25262							
-76.61	-76.16	-73.26	-70.21	-67.01	-63.68	-60.20	-56.62
-52.91	-49.05	-45.08	-40.97	-36.74	-32.37	-27.89	-23.29
-18.55	-13.69	-8.70	-3.58	1.64	6.99	12.45	18.04
23.73							
1.239	1.253	1.346	1.437	1.528	1.618	1.708	1.797
1.885	1.972	2.059	2.144	2.231	2.315	2.400	2.484
2.567	2.650	2.733	2.815	2.897	2.978	3.060	3.141
3.220							
4911.	4901.	4881.	4849.	4812.	4770.	4727.	4681.
4639.	4593.	4547.	4501.	4452.	4399.	4350.	4297.
4245.	4192.	4133.	4081.	4025.	3969.	3913.	3861.

3840.							
20.268	21.	22.	23.	24.	25.	26.	27.
28.	29.	30.	31.	32.	32.976		
16.08	16.78	17.74	18.72	19.72	20.74	21.79	22.89
24.04	25.27	26.61	28.15	30.08	35.42		

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-1.3180607E-04	-1.7026696E-04	-2.1873437E-04	-2.5922335E-04	-3.1173105E-04

-3.6397233E-04	-4.2257714E-04	-4.5541749E-04	-5.0527305E-04	-5.4852158E-04
-5.8649584E-04	-6.1718419E-04	-6.4380987E-04	-6.5827104E-04	-6.5781804E-04
-6.4924148E-04	-6.2883272E-04	-5.9352177E-04	-5.5021366E-04	-4.9570493E-04
-4.3643903E-04	-3.7869989E-04	-3.2988888E-04	-2.9135311E-04	-2.7009731E-04
-2.7696572E-04	-2.9812312E-04	-3.5004592E-04	-4.2455082E-04	-5.2401202E-04
-6.4125592E-04	-7.8212495E-04	-9.3448052E-04	-1.0934784E-03	-1.2559322E-03
-1.3698538E-03	-1.5478358E-03	-1.7219023E-03	-1.8920438E-03	-2.0561721E-03
-2.2143473E-03	-2.4177387E-03	-2.6272401E-03	-2.8407149E-03	-2.9235301E-03
-3.2097408E-03	-3.4133869E-03	-3.4292715E-03	-4.0583221E-03	-4.0351868E-03
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-7.6073285E-03	-7.9515444E-03	-9.1273819E-03	-9.5657506E-03	-1.1015059E-02
-1.1959132E-02	-1.3886189E-02	-1.5505519E-02	-1.7400006E-02	-2.0124586E-02
-2.2408441E-02	-2.3006439E-02	-2.3612257E-02	-2.1131850E-02	-1.5787078E-02
-7.2297747E-03	-1.1157932E-02	2.0572108E-04	9.1201507E-03	-3.6886842E-02
-2.5967306E-01	2.0399673E-02	4.1266163E-02	6.8570651E-02	1.4766631E-01
4.1671141E-02	8.3815085E-02	1.2820967E-01	1.7331713E-01	2.2031547E-01
2.6879575E-01	3.1955518E-01	3.7255940E-01	4.2889084E-01	4.8814042E-01
5.5015638E-01	6.1401927E-01	6.6175290E-01	7.4882307E-01	8.2030192E-01
8.9316323E-01	9.6889537E-01	1.0395381E+00	1.1158471E+00	1.1918611E+00
1.2680118E+00	1.3436317E+00	1.4155863E+00	1.4938576E+00	1.5657673E+00
1.6369293E+00	1.7064442E+00	1.7737101E+00	1.8403582E+00	1.9056878E+00
1.9713662E+00	2.0390411E+00	2.1107021E+00	2.1868961E+00	2.2692860E+00
2.3605869E+00	2.4577571E+00	2.5647236E+00	2.6795942E+00	2.8029003E+00
2.9331360E+00	3.0713863E+00	3.2149294E+00	3.3623746E+00	3.5129883E+00
3.6532274E+00	3.8122308E+00	3.9723517E+00	4.1335542E+00	4.2953206E+00
4.4572955E+00	4.6326102E+00	4.8109381E+00	4.9917539E+00	5.1482192E+00
5.3505627E+00	5.5385032E+00	5.6917803E+00	5.9679756E+00	6.1196071E+00
6.4955823E+00	6.7236159E+00	7.0008332E+00	7.2845818E+00	7.5091781E+00
7.7573489E+00	7.9939722E+00	8.3571042E+00	8.6083924E+00	9.0096826E+00
9.3389942E+00	9.8044979E+00	1.0229200E+01	1.0686035E+01	1.1241795E+01
1.1740489E+01	1.2016333E+01	1.2275667E+01	1.2205924E+01	1.1833711E+01
1.1143704E+01	1.1728386E+01	1.0774412E+01	1.0186019E+01	1.4999411E+01
3.7406308E+01	1.0508182E+01	9.6191112E+00	8.3929369E+00	4.3831287E+00
-5.7318471E-02	-1.8093034E-01	-4.9784230E-01	-8.8737394E-01	-1.4439885E+00
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-8.9079311E+00	-1.0891583E+01	-1.3194512E+01	-1.5409693E+01	-1.7982500E+01
-2.0641264E+01	-2.3494803E+01	-2.5827529E+01	-2.8601520E+01	-3.1270310E+01
-3.3868301E+01	-3.6312903E+01	-3.8676869E+01	-4.0770123E+01	-4.2521120E+01
-4.4057432E+01	-4.5291856E+01	-4.6171278E+01	-4.6823811E+01	-4.7185354E+01
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-8.8378554E+01	-9.3209590E+01	-9.7775742E+01	-1.0205513E+02	-1.0598185E+02
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-9.8067031E+01	-9.7440413E+01	-3.8944428E+01	2.2018214E+00	-1.5324378E+02
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-3.4852970E-01	-2.3328599E+00	-2.0682478E+00	-3.2165717E+00	-2.6094543E+00
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3.2576079E+02	3.2333676E+02	3.1249379E+02	2.8602308E+02	2.4109665E+02
1.8228715E+02	1.0647785E+02	1.1968543E+01	-9.6472164E+01	-2.2083220E+02
-3.5521484E+02	-4.9429203E+02	-6.3011102E+02	-7.5967443E+02	-8.7793619E+02
-9.7611348E+02	-1.0620580E+03	-1.1236298E+03	-1.1665448E+03	-1.1896026E+03
-1.1965205E+03	-1.1861179E+03	-1.1663516E+03	-1.1427383E+03	-1.1180923E+03

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-7.3317710E+02  -7.1729678E+02  -6.1916306E+02  -5.2271128E+02  -5.3825987E+02
-5.1531466E+02  -5.1639302E+02  -3.6579871E+02  -3.6543501E+02  -1.8416297E+02
-8.7846858E+01   1.5419294E+02   3.5588009E+02   5.7942490E+02   8.7722455E+02
 1.1212214E+03   1.1541824E+03   1.1518611E+03   9.4203092E+02   5.4030442E+02
-3.5545003E+01   1.5041468E+02  -5.6987252E+02  -8.9772310E+02   1.9715175E+03
 1.5643871E+04         0.0E+00         0.0E+00         0.0E+00         0.0E+00
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 9.0641995E+03   8.6428251E+03   7.4271301E+03   6.3105084E+03   6.3673451E+03
 6.0708932E+03   6.0532802E+03   4.8294821E+03   4.9320575E+03   3.5624987E+03
 2.9059444E+03   1.1351017E+03  -3.1705787E+02  -1.8692257E+03  -3.8552011E+03
-5.4197643E+03  -5.4462613E+03  -5.1573924E+03  -3.6215951E+03  -9.1656659E+02
 2.7670921E+03   2.0174573E+03   6.5948069E+03   8.2338689E+03  -9.3307466E+03
-9.3572403E+04         0.0E+00         0.0E+00         0.0E+00         0.0E+00
0.0005  0.0010  0.0015  0.0020  0.0025  0.0030  0.0035  0.0040  0.0045  0.0050
0.0055  0.0060  0.0065  0.0070  0.0075  0.0080  0.0085  0.0090  0.0095  0.0100
0.0105  0.0110  0.0115  0.0120  0.0125  0.0130  0.0135  0.0140  0.0145  0.0150
0.0155  0.0160  0.0165  0.0170  0.0175  0.0180  0.0185  0.0190  0.0195  0.0200
0.0205  0.0210  0.0215  0.0220  0.0225  0.0230  0.0235  0.0240  0.0245  0.0250
0.0255  0.0260  0.0265  0.0270  0.0275  0.0280  0.0285  0.0290  0.0295  0.0300
0.0305  0.0310  0.0315  0.0320  0.0325  0.0330  0.0335  0.0340  0.0345  0.0350
0.0355  0.0360  0.0365  0.0370  0.0375  0.0380  0.0385  0.0390  0.0395  0.0400
0.0405  0.0410  0.0415  0.0420  0.0425  0.0430  0.0435  0.0440  0.0445  0.0450
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    0.40084907E-04            0.0E+00             0.0E+00            0.0E+00
   -0.27176666E+02     0.21129340E+03      0.13364318E+02    -0.19311670E+04
    0.67461013E+04            0.0E+00             0.0E+00            0.0E+00
   -0.71967724E-02     0.14495527E-02      0.32403130E-02    -0.44640177E-02
           0.0E+00            0.0E+00             0.0E+00            0.0E+00
    0.17724540E+01    -0.44368880E+02      0.20554680E-01            0.0E+00
           0.0E+00            0.0E+00             0.0E+00            0.0E+00
    0.20006200E+01    -0.50097080E+02      0.10044000E+01     0.17484950E-01
           0.0E+00            0.0E+00             0.0E+00            0.0E+00
   -0.87239000E+03     0.26248000E+02     -0.09787200E+01     0.00271270E+01
           0.0E+00            0.0E+00             0.0E+00            0.0E+00
    0.10111000E+04    -0.29485000E+02      0.25312000E+01    -0.00666590E+01
           0.0E+00            0.0E+00             0.0E+00            0.0E+00
   -0.22172000E+02     0.52157000E+01     -0.02737800E+01     0.58282000E-02
    0.04826500E+01    -0.29189000E-01             0.0E+00            0.0E+00
   -0.06839500E+01     0.18552000E+01     -0.00378920E+01     0.40527000E+02
    0.54573000E+01    -0.32436000E+01     -0.01769100E+01     0.00641000E+01
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EXAMPLE CASE DATA DECK LISTING

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C30569
 10     FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69
1.0     C.0     1.1     0.315   1.25    0.405   1.5     0.49
1.75    C.535   2.0     0.568   2.25    0.585   2.5     0.6
2.75    C.603   3.0     0.605
 16     FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69
0.0     C.0     0.02    0.065   0.04    0.13    0.06    0.195
0.08    C.26    0.10    0.32    0.12    0.377   0.14    0.431
0.16    C.479   0.18    0.52    0.2     0.56    0.22    0.593
C.24    C.62    0.26    0.645   0.28    0.665   0.3     0.677
 13     FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69
1.0     0.0     1.1     0.87    1.2     1.34    1.3     1.62
1.4     1.85    1.5     2.01    1.6     2.14    1.7     2.25
1.8     2.32    1.9     2.39    2.0     2.42    2.1     2.44
2.2     2.44
 15     FINAL CURVE BASED ON TEST DATA,L.H.,T.R.,2-7-69
0.0     C.0     0.05    0.027   0.1     0.056   0.15    0.083
C.2     C.11    0.25    0.133   0.3     0.155   0.35    0.173
0.4     0.187   0.45    0.195   0.5     0.197   0.55    0.192
0.6     0.177   0.65    0.15    0.7     0.107
  3 21  FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69
.C000005 .000001 .C00002
0.0     C.04    0.08    0.10    0.117   0.121   0.14    0.16
C.18    C.20    0.22    0.24    0.26    0.28    0.32    0.36
0.38    C.40    0.415   0.422   0.424
.0000373 .0000380 .0C00383 .0000383 .00C0383 .0000455 .0000463 .0000465
.C000462 .0000457 .C000450 .0000440 .0000430 .0000418 .0000388 .0000339
.0000295 .0000205 .0000   .0      .0
.0C00398 .0000402 .CC00405 .0000406 .00C0406 .0000480 .0000485 .0000487
.0000486 .0000482 .0000478 .0000470 .0000459 .0000445 .0000415 .000037
.0000335 .0000266 .0C00204 .0000   .0
.C000398 .0000402 .C000405 .0000406 .0000406 .0000480 .0000485 .0000487
.0000486 .0000482 .0000478 .0000470 .0000459 .0000445 .0000415 .000037
.0000335 .0000285 .C000238 .0000134 .0
  3 21  FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69
.0000005 .000001 .C00002
C.0     C.04    0.08    0.10    0.117   0.121   0.14    0.16
C.18    C.20    0.22    0.24    0.26    0.28    0.32    0.36
C.38    C.40    0.415   0.422   0.424
C.0     .16     .315    .383    .44     .485    .518    .548
.575    .556    .611    .618    .618    .611    .588    .537
.471    .354    .0      .0      .0
C.0     .17     .325    .396    .456    .500    .533    .564
.591    .613    .626    .632    .631    .625    .604    .561
.501    .402    .265    .0      .0
C.0     .17     .325    .396    .456    .500    .533    .564
.591    .613    .626    .632    .631    .625    .604    .561
.510    .422    .31     .15     .0
  2 14  FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69
C.0     C.0000045
C.0     C.2     0.4     0.54    0.55    0.6     0.7     0.8
C.9     1.0     1.1     1.2     1.305   1.35
.00001563 .0000148 .C000139 .0000132 .00C01495 .00001472 .00001405 .000013
.CC00115 .0000C96 .C0000725 .0000042 .0
.0000161 .0000154 .00001448 .0000138 .0C001565 .0000154 .0000146 .00001345
.00CC1195 .00C01023 .0000062 .0000054 .0000018 .0
  2 14  FINAL CURVE BASED ON TEST DATA,T.N.,2-13-69
```

```
C.0      C.0000045
C.0      C.2      C.4      0.54     0.55     0.6      0.7      0.8
C.S      1.0      1.1      1.2      1.305    1.35
C.0      C.15     0.28     0.355    0.415    0.45     0.496    0.527
C.544    C.531    C.475    0.367    0.0      0.0
C.0      C.16     0.30     0.39     0.45     0.484    0.53     0.56
C.575    0.567    0.525    0.44     0.22     0.0
    1    1    2    2        -1
73.0     84.95    14.7     500.     0.320    37.6     0.05
C.8333   34.84    5.445    5.26     1.1776   0.8125   78.5     36.5
17.72    C.021    0.C2
   14
62.5072  443.28   72.5072  443.28   73.2764  443.58   74.0512  486.06
74.5134  510.10   75.5952  518.83   76.5212  523.76   77.5502  527.52
78.5274  530.41   8C.0202  532.43   81.5124  533.59   82.5942  534.16
84.0352  535.32   85.C124  535.32
   20
62.5501  15.16    72.5501  15.16    73.2445  15.16    73.3219  20.61
73.5017  22.38    74.0167  36.44    74.5051  67.60    75.0457  69.60
75.5095  73.65    76.0235  96.48    77.0017  143.86   78.0051  206.52
79.0085  265.57   80.0119  294.23   8C.5781  305.17   81.0931  312.78
82.0191  319.61   83.0225  329.89   84.0007  337.17   85.0041  337.05
    2
70.      100C.    86.      2000.
   13
62.5168  32.695   72.5168  32.695   72.7484  32.61    72.8504  32.55
73.0052  32.68    73.494   31.975   73.9834  31.89    75.0124  29.81
78.1004  24.295   80.0042  21.61    82.C114  21.045   84.0192  19.705
85.022   18.74
```

APPENDIX C

NOMENCLATURE

Appendix C

I. INDUCER/MAIN STAGE PUMP DESIGN AND PERFORMANCE NOMENCLATURE

ϕ_{ms}	Flow coefficient mainstage impeller discharge C_m2/μ_2
C_m2	Volumetric flow rate/impeller discharge area
μ_2	Impeller tip velocity
η_p	Mainstage pump efficiency $\frac{HDAIS - HDI}{HDAIS - HDA} \times (100)$
η_{pIS}	Low speed pump efficiency (inducer-stator) $\frac{HSI - HDIIS}{HSI - HDAIS} \times (100)$
HSI	Suction line enthalpy
HDIIS	Stator discharge ideal enthalpy
HDAIS	Stator discharge actual enthalpy
HDI	Mainstage discharge ideal enthalpy
HDA	Mainstage discharge actual enthalpy
ψ_{IS}	Low speed stage (inducer-stator) head coefficient $[P_{TDS}\ (SVDS) - P_{TSL}\ (SVSL)]\ g/\mu_{ID}^2$
P_{TSL}	Suction line total pressure
P_{TDS}	Stator discharge total pressure
SVSL	Specific volume in suction line
SVDS	Specific volume at stator discharge
g	Acceleration of gravity
μ_{ID}	Inducer rotor tip velocity
ψ_{ms}	$[(P_{DT} - P_{TDS})\ \frac{(SVDS + SVD)}{2}]\ g/\mu_2^2$
P_{DT}	Mainstage pump discharge total pressure
SVD	Specific volume at pump discharge
$NPSH_{tk}$	Net positive suction head within the run tank
HSV or $NPSH_{ms}$	Net positive suction head at the inlet to mainstage pump (within the interstage)

ϕ_{ID}	Flow coefficient at inducer rotor discharge Cm_{ID}/μ_{ID}
Cm_{ID}	Volumetric flow rate/inducer rotor discharge area
ϕ_{II}	Flow coefficient at inducer rotor inlet Cm_{II}/μ_{II}
Cm_{II}	Volumetric flow rate/inducer rotor inlet area
μ_{II}	Inducer rotor inlet tip velocity
S_I	Suction specific speed at inducer rotor inlet
τ	Cavitation parameter = $NPSH_L/\mu_{II}^2/g$
$NPSH_L$	Net positive suction head on the suction line
N_{ms}	Mainstage impeller rotational speed
N_I	Inducer rotor rotational speed
Q	Volumetric flow at mainstage discharge

II. INDUCER TURBINE DESIGN AND PERFORMANCE NOMENCLATURE

Symbol	Description	Units English	Units SI
a	Local speed of sound	ft/sec	m/s
A	Area	$in.^2$	cm^2
b	Axial blade chord	inch	cm
c	Blade chord	inch	cm
C_o	Spouting velocity	ft/sec	m/s
c_p	Specific heat at constant pressure	Btu/lb-°R	J/kg-°K
d	Throat opening at mean radius	inch	cm
D_h	Hydraulic diameter	ft	m
g	Acceleration of gravity (32.174)	ft/sec^2	m/s^2
h	Blade height	inch	cm
H	Specific enthalpy	Btu/lb	J/kg

Appendix C

Symbol	Description	Units English	Units SI
J	Mechanical equivalent of heat (778.2)	ft-lb/Btu	J
K	Velocity coefficient		
M	Absolute Mach number		
n	Number of blades or vanes		
N	Rotational speed	rpm	rad/s
P	Static pressure	lb/in.^{2}	N/cm^2
P_t	Total pressure	lb/in.^{2}	N/cm^2
PR_s	Total-to-static pressure ratio		
r	Radius	inch	cm
R	Gas constant	$\frac{\text{lbf-ft}}{\text{lbm-°R}}$	$\frac{\text{N-m}}{\text{kg-°K}}$
Re	Reynolds number		
s	Blade pitch	inch	cm
t	Blade maximum thickness	inch	cm
T	Static temperature	°R	°K
T_t	Total temperature	°R	°K
T_{tr}	Total relative temperature	°R	°K
U_m	Wheel velocity at blade mean radius	ft/sec	m/s
V	Absolute velocity	ft/sec	m/s
W	Velocity relative to rotor	ft/sec	m/s
$\dot{W}$	Mass flow	lb/sec	kg/sec
α (alpha)	Angle of absolute gas velocity	degrees	degrees
β (beta)	Angle of relative gas velocity	degrees	degrees
γ (gamma)	Ratio of specific heats, $\gamma = \frac{C_p}{C_v}$		

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Symbol	Description	Units English	Units SI
Δ (delta)	Prefix to indicate a change		
δ	Deviation angle		
η_s (eta)	Turbine efficiency based on total-to-static pressure ratio		
ρ (rho)	Density	lb/ft^3	kg/m^3
σ	Deviation angle		
θ	Blade camber angle		
$\Delta\theta$	Induced angle		
ε	Gas turning angle		
ξ	Loss coefficient		

Subscripts

0'	Main turbine flange inlet
1'	Main turbine first stator inlet
2'	Main turbine last rotor exit
0	Inducer turbine stator inlet
1	Inducer turbine stator exit
2	Inducer turbine rotor exit
3	Inducer turbine exhaust flange
a	Blade annulus
b	Blade
c	Bearing coolant, or blade clearance annulus
h	Hydraulic
i	Isentropic
m	At mean radius
n	Nozzle
r	Rotor, radius, or relative

Subscripts

s	Static
t	Trailing edge, total, or turbine
u	Tangential component
x	Axial component

III. COMPUTER ANALYSIS NOMENCLATURE

Symbol	Definition	Units
a	Sonic velocity, suction line	ft/sec
A	Area	$in.^2$
C	Loss coefficient	-
C_p	Constant pressure specific heat	Btu/lb-°R
Co	Isentropic spouting velocity	ft/sec
D	Suction line diameter	ft
f	Friction factor	-
FP	Flow parameter	$in.^2 {}^\circ R^{1/2}/sec$
g	Gravatational constant	ft/sec^2
h	Enthalpy	Btu/lb
H	Head	ft
I	Polar moment of inertia	$in.-lb-sec^2$
J	Mechanical equivalent of heat	$778.16 \frac{ft-lb}{Btu}$
K	Darey head loss coefficient	-
L	Suction line length	ft

Appendix C

Symbol	Definition	Units
N	Rotative speed	rpm
NPSP	Net positive suction pressure	psi
NPSH	Net positive suction head	ft
P	Pressure	psia
Pr	Pressure ratio	-
Q	Volumetric flow rate	gpm
r	Mean blade radius	in.
R	Gas constant	ft/°R
SHP	Shaft power	Hp
SV	Specific volume	ft^3/lb
t	Time	sec
T	Temperature	°R
U	Mean blade velocity	ft/sec
V	Fluid velocity	ft/sec
$\dot{w}$	Flow rate	lb/sec
ρ	Density	lb/ft^3
γ	Specific heat ratio	-
η	Efficiency	-
τ	Torque	ft-lb
Δ	Change	-

Subscripts

sL	Suction line
I	Inducer
i	Inlet

Subscripts

TK	Tank
mT	Main turbine
IT	Inducer turbine
m	Main
P	Pump
e	Exhaust or discharge
n	Index
id	Ideal
VP	Vapor

Superscripts

	Total state

IV. FORTRAN NOMENCLATURE

MAIN PROGRAM

Symbol	Definition	Units
AI)	Suction line flow area	in.^{2}
(COI)	Inducer turbine isentropic spouting velocity	ft/sec
(COM)	Main turbine isentropic spouting velocity	ft/sec
(CPM)	Main turbine constant pressure specific heat	Btu/lb-°R
(CT)	Constant	-
D)	Suction line diameter	ft
(DHI)	Inducer head rise	ft
(DHM)	Main pump head rise	ft

Appendix C

Symbol	Definition	Units
(DHNI)	Inducer normalized head rise	ft/rpm^2
(DHNM)	Main pump normalized suction head	ft/rpm^2
(DHTI)	Inducer turbine enthalpy drop	Btu/lb
(DHTII)	Inducer turbine isentropic enthalpy drop	Btu/lb
(DHTM)	Main turbine enthalpy drop	Btu/lb
(DPI)	Inducer pressure rise	psi
(DPM)	Main pump pressure rise	psi
(DTIME)	Incremental time change	sec
(EATPI)	Inducer efficiency	-
(EATPM)	Main pump efficiency	-
(EATTI)	Inducer turbine efficiency	-
(EATTM)	Main turbine efficiency	-
(FPI)	Inducer turbine flow parameter	-
(FPM)	Main turbine flow parameter	-
FRI)	Suction pipe friction coefficient	-
(GAMM)	Main turbine specific heat ratio	-
II)	Inducer rotating assembly moment of inertia	in.-lb-sec^2
IM)	Main rotating assembly moment of inertia	in.-lb-sec^2
(NI, NIFIN)	Inducer shaft speed	rpm
NM	Main shaft speed	rpm
(NPSHI)	Inducer net positive suction head	ft
(NPSHM)	Main pump net positive suction pressure	ft
(NPSNI)	Inducer normalized suction head	ft/rpm^2

Appendix C

Symbol	Definition	Units
(NPSNM)	Normalized net positive suction pressure	ft/rpm^2
(NPSPI)	Inducer net positive suction pressure	psi
(NPSPM)	Main pump net positive suction pressure	psi
PII, P2)	Inducer inlet pressure	psia
(PMI, PMIF)	Main pump inlet pressure	psia
(PRI)	Inducer turbine pressure ratio	-
(PRM, PRMF)	Main turbine pressure ratio	-
(PTEI)	Inducer turbine static exhaust pressure	psia
(PTII)	Inducer inlet total pressure	psia
PTK, P1)	Tank pressure	psia
(PTME)	Pump discharge total pressure	psia
(PTTEM)	Main turbine exhaust pressure	psia
(PTTII)	Inducer turbine inlet total pressure	psia
PTTIM	Main turbine inlet total pressure	psia
(PVPII)	Inducer inlet vapor pressure	psia
(PVPMI)	Main pump inlet vapor pressure	psi
(QII)	Inducer inlet volumetric flow rate	gpm
(QMI)	Main pump inlet volumetric flow rate	gpm
(QNI)	Inducer normalized flow rate	gal/rev
QNM)	Main pump normalized flow rate	gal/rev
(SHPAV)	Arithmetic average of inducer and inducer turbine power	hp
(SHPPI, SHPIF)	Inducer shaft power	hp
(SHPPM)	Main pump shaft power	hp

Appendix C

Symbol	Definition	Units
(SHPTI)	Inducer turbine shaft power	hp
(SHPTM)	Main turbine shaft power	hp
(SLOP1)	Finite rate of change of main turbine flow rate with main turbine pressure ratio	lb/sec
(SLOP2)	Finite rate of change of inducer turbine flow rate with main turbine pressure ratio	lb/sec
(SLOP3)	Finite rate of change of inducer power with speed	$\frac{hp}{rpm}$
(SLOP4)	Finite rate of change of inducer turbine power with speed	$\frac{hp}{rpm}$
(SOV)	Sonic velocity in suction line	ft/sec
(SVII)	Inducer inlet specific volume	
(SVMI)	Main pump inlet specific volume	ft^3/lb
TIME)	Time	sec
TMINT)	Initial time	sec
(TORPI)	Inducer torque	lb-ft
(TORPM)	Main pump torque	lb-ft
(TORTI)	Inducer turbine torque	lb-ft
(TORTM)	Main turbine torque	lb-ft
TPII)	Inducer inlet fluid temperature	°R
(TPMI)	Main pump inlet fluid temperature	°R
(TTEM)	Main turbine exhaust temperature	°R
(TTEG, TTEI)	Inducer turbine exhaust gas temperature	°R
(TTII)	Inducer turbine inlet temperature	°R
TTIM)	Main turbine inlet temperature	

Appendix C

Symbol	Definition	Units
(UCOI)	Inducer turbine velocity ratio	-
(UI)	Inducer turbine mean blade speed	ft/sec
(UM)	Main turbine mean blade speed	ft/sec
(W1)	Tank out weight flow rate	lb/sec
(WP, W2)	Pump weight flow rate	lb/sec
(WTI, WTIF)	Inducer turbine flow rate	lb/sec
(WTM, WTMF)	Main turbine flow rate	lb/sec
XLINE)	Suction pipe length	ft
XLOSS)	Exhaust system loss coefficient	-

) Designates input value

( ) Designates computed value

NOTE: Only the FORTRAN symbols of the MAIN program are shown. Those symbols appearing in the subprograms are dummy ones.

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